

**BIOMASS PRODUCTION, YIELD AND QUALITY RESPONSE OF  
SPRING WHEAT TO SOIL TILLAGE, CROP ROTATION AND  
NITROGEN FERTILISATION IN THE SWARTLAND WHEAT  
PRODUCING AREA OF SOUTH AFRICA**

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## Chapter 5

### **Effect of soil tillage, crop rotation and nitrogen application rates on some growth components of spring wheat (*Triticum aestivum* L.) in the swartland wheat producing area of South Africa**

#### **Abstract**

Studies on spring wheat growth components were conducted during the 2000 and 2001 growing seasons in a long-term tillage and crop rotation trial, which started in 1976. Four tillage methods, namely conventional tillage (CT), tine tillage (TT), minimum tillage (MT), and no-tillage (NT) were compared. Crop rotation systems used were continuous wheat (WW) and wheat/lupin/wheat/canola (WLWC). Three rates of N-fertilisers (60, 100 and 140 kg N ha<sup>-1</sup>) were applied. All treatments received 60 kg N ha<sup>-1</sup> at planting, while the 100 and 140 kg N ha<sup>-1</sup> treatments received additional top-dressings of 40 kg N ha<sup>-1</sup> at tillering and stem elongation stages respectively.

Tillage methods had a significant effect on the number of tillers per square metre, leaf area index and dry mass in both the 2000 and 2001 growing seasons. In the 2000 growing season plants on no-till plots produced the highest tiller numbers, larger leaf area and the highest dry mass. Contrasting results were found during 2001.

Crop rotation had no significant effect on number of tillers per square metre, while significant effects were only noticed at the flag leaf stage for leaf area index. Higher dry mass was produced on crop rotation plots compared with monoculture.

Application of different rates of nitrogen had a significant effect on the number of tillers per square meter at stem elongation stage only, leaf area index and dry mass production at all sampling stages during the 2000 season, while no significant effects were found during the 2001 growing season. Generally higher N rates increased the above mentioned growth components.

**Key words:** Crop rotation, growth components, leaf area index, tiller number, tillage methods, spring wheat

#### **Introduction**

In contrast to the effect on yield and grain protein contents (Kirkegaard *et al.*, 1997; López-Bellido, López-Bellido, Castillo & López-Bellido, 2000; López-Bellido & López-

Bellido, 2001), little research have been conducted on the effect of production techniques such as method of tillage, crop rotation and nitrogen fertilisation on wheat growth components such as tiller numbers, leaf area (total and duration) and dry mass production under Mediterranean-type climates. These components determined the eventual yield in several ways (Stoskopf, 1981; Frederick & Bauer, 1999).

Generally only small percentages of the tillers produced actually survived to produce ears, but several studies (Stoskopf, 1981; Anadif & Hisse, 2000) reported that high tiller numbers are essential for high yield because of their effect on kernels per m<sup>2</sup> (Frederick & Bauer, 1999).

Leaf area per plant and specially leaf area index are considered to be one of the most important morphological traits that are associated with wheat yield. Data from Borghi (1999) showed that dry mass increases are associated with larger leaves that stay green longer, taller stems and larger number of ear bearing tillers.

Growth components are affected by physical, chemical and biological soil properties and climatic conditions (Galantini *et al.* 2000), and because these soil properties are in turn affected by tillage methods, crop rotations and nitrogen fertilisation (López-Fando & Almendros, 1995; Hao *et al.*, 2000; Young & Ritz, 2000), it may be expected that growth components will also be affected by these production techniques.

Under cool climatic conditions, Carter (1994) showed that tillers per plant were not influenced by tillage methods. Plant population and plant dry mass production from early seedling to the heading stage were also not consistently influenced by tillage treatments in his study. In semi-arid environments, López-Fando & Almendros (1995) as well as Unger (1994) showed that no-tillage had little or no effect on crop growth parameters. Agenbag & Maree (1988) however found that total leaf-area duration of wheat crops increased with increasing tillage depth in a shallow stony soil under a Mediterranean-type of climate. They related these results to larger leaf-areas of single plants due to deeper rooting in the well-tilled soil.

Crop rotations may also affect wheat growth components. In a study done by Galantini *et al.* (2000), wheat-legume rotations resulted in larger growth and higher values for yield components compared to continuous wheat or wheat rotated with natural grass pastures.

Wheat growth components such as tillering and leaf growth are dependent on sufficient supply of nitrogen (Borghi, 1999). Frederick & Camberato, (1995a, 1995b) reported that application of below the recommended rates of nitrogen resulted in lower leaf area indices and thus lower photosynthesis rates at anthesis which may cause a reduced number of kernels per m<sup>2</sup> at maturity, compared to recommended rates of nitrogen. The effect of N-fertilisers on dry mass production varies between years, mainly due to the amount and

distribution of precipitation (Garabet, Wood & Ryan, 1998; Galantini *et al.*, 2000). Dry mass production increased by the addition of N fertiliser up to 100-150 kg ha<sup>-1</sup> in South Australia (McDonald, 1992). Significant increase in dry mass with application of N were also measured at anthesis, but the relative response were less than those at 10 weeks after sowing. Generally this increase in the dry mass production was often of no benefit to yield. The aim of this experiment was to study the growth and development of spring wheat under a Mediterranean-type climate in the Republic of South Africa in response to different tillage methods, crop rotation and nitrogen fertilisation.

## **Materials and methods**

Studies on spring wheat growth components (plant numbers per m<sup>2</sup>, tiller numbers, leaf area and total dry mass) were conducted during the 2000 and 2001 growing seasons as part of a long-term tillage and crop rotation trial. Although the tillage treatments tested were used since 1976, present crop rotations and nitrogen application rates were only applied since 1990. Description of locality, climate, experimental layout and treatments as well as data analysis are presented in Chapter 3.

### **Plant samplings**

Plant numbers per square metre for different tillage methods and crop rotation treatments were counted at approximately 30 days from planting. Three randomised chosen sub-plots of 0.5 m<sup>2</sup> were counted per plot.

Wheat plants were sampled at the following growth stages. The first sampling at tillering stage (S<sub>1</sub>) which was about 48 days from planting. The second sampling at stem elongation (S<sub>2</sub>) which was about 65 days from planting. The third sampling at flag leaf (S<sub>3</sub>) which was about 85 days from planting for 2000 growing season only. The fourth sampling at anthesis (S<sub>4</sub>) which is about 105 days from planting. Ten plants were taken from each sub-plot at each sampling date. After tiller numbers per plant were counted, the plants were separated in to leaves, stems and spikes. Leaf area of green leaves per plant was measured, while leaf area index was calculated by multiplying leaf area per plant with the number of plants established per square metre of land. Leaves, stems and spikes were separately dried at 80 °C for 48 hours and weighed. Total dry mass (DM) in grams per square metre was calculated by multiplying total dry mass per plant (g. plant<sup>-1</sup>) with the number of the plants established per square metre.



## Results and discussions

### Plant numbers per square metre

Mean plant numbers per  $m^2$  varied between 183.1 for the 2000 growing season and 217.6 for the 2001 growing season (Table 5.1), showing that the population density of 200 plants per  $m^2$  aimed for, was closely met in both years. Although slight differences were found with both methods of tillage and crop rotations, differences were not significant at  $P(0.05)$ . Due to the absence of large differences, treatment trends for plant components such as tiller number, leaf area and dry mass on a per plant and per square metre basis were found to be the same. It was therefore decided to discuss all data on a per  $m^2$  basis only.

**Table 5.1** Wheat plant numbers per  $m^2$  as effected by different tillage methods and different crop rotations during the 2000 and 2001 growing seasons at Langgewens Experimental Farm

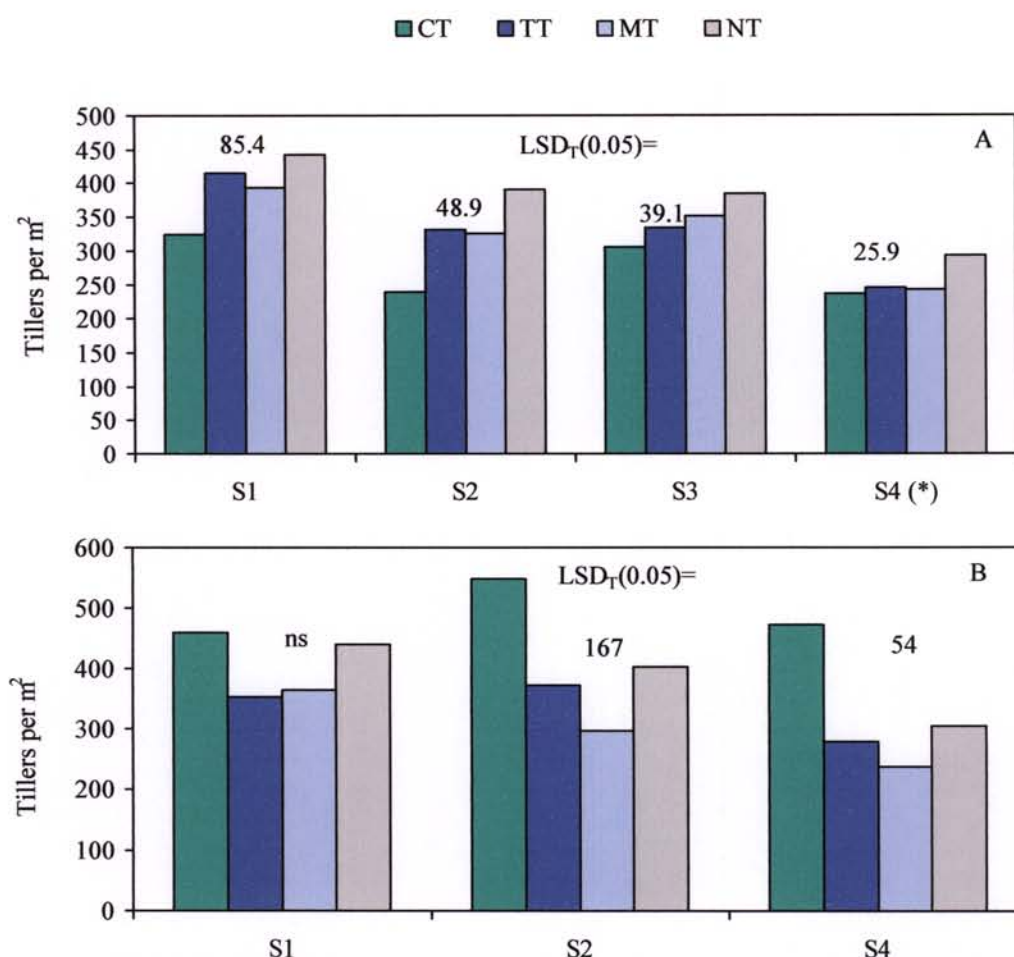
Tillage methods	Plants numbers ( $m^{-2}$ )	
	2000	2001
Conventional till.	170.8	225.0
Tine till.	184.5	222.8
Minimum till.	185.3	187.5
No- till.	192.0	235.0
Mean	183.1	217.6
LSD <sub>T</sub> (0.05)	ns	ns
C.V. %	12.3	16.8
Crop rotation		
Wheat/wheat	190.5	-----
Wheat/lupin/canola	175.8	-----
LSD <sub>T</sub> (0.05)	ns	

----- No crop rotation during 2001

### Number of tillers per square metre

Significant tillage x nitrogen and crop rotation x nitrogen interactions were found for the number of tillers per  $m^2$  at some sampling stages. These interactions will however not be discussed because similar trends were not found for other components and interactions for tillers per  $m^2$  were not shown for all sampling stages.

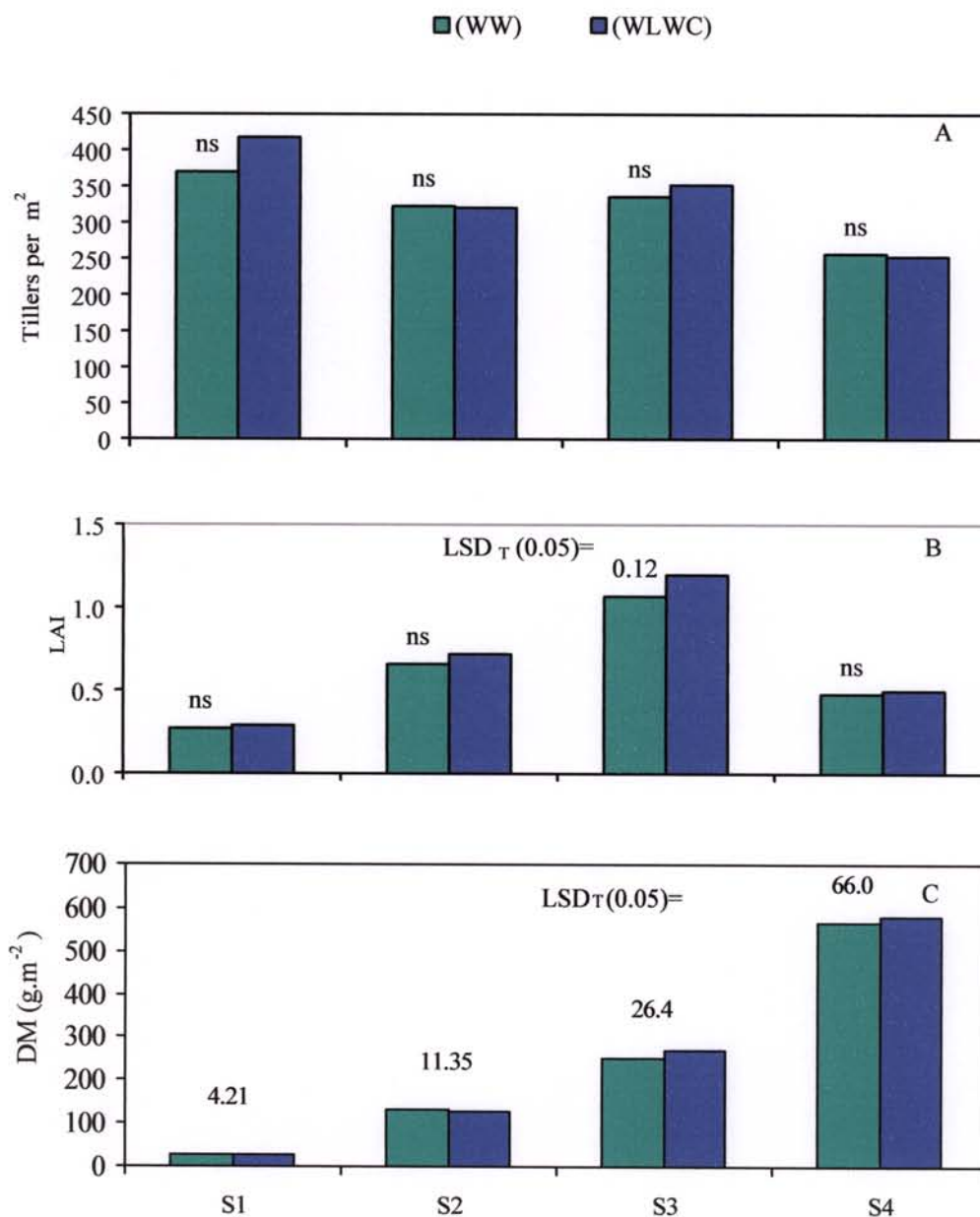
Number of tillers per m<sup>2</sup> was significantly affected by the different tillage methods in both the 2000 and 2001 growing seasons (Fig.5.1). In both seasons, more than 300 tillers per m<sup>2</sup> were produced initially, but tiller numbers decreased toward the anthesis coinciding with the decreased in mineral-N content of the soil as shown in Chapter 4.



**Figure 5.1** Effect of conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no-tillage (NT) on tiller numbers per m<sup>2</sup> of spring wheat at different growth stages (S<sub>1</sub> tillering stage, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm  
(\*) fertile tillers

In the 2000 growing season which was characterised by dry conditions, significant differences were found between tillage methods at all growth sampling stages. The highest tiller number was produce by plants on NT plots, while plants on CT plots produced the least (Fig.5.1a). This might be related to better soil moisture conservation and greater water use efficiency with NT under dry conditions (Lawrence *et al.*, 1994; Martinez, O'Leary & Connor, 1995; Pratley 1995; Lafond *et al.*, 1996; Strong *et al.*, 1996). During the 2001 growing season, which was characterised by wet conditions, CT resulted in the highest tiller number at all growth sampling stages (Fig.5.1b). These results supported findings by

Frederic & Bauer, (1999) as well as Anadif & Hisse, (2000), who attributed differences in tiller numbers to factors such as climate, soil properties and cultural practices.

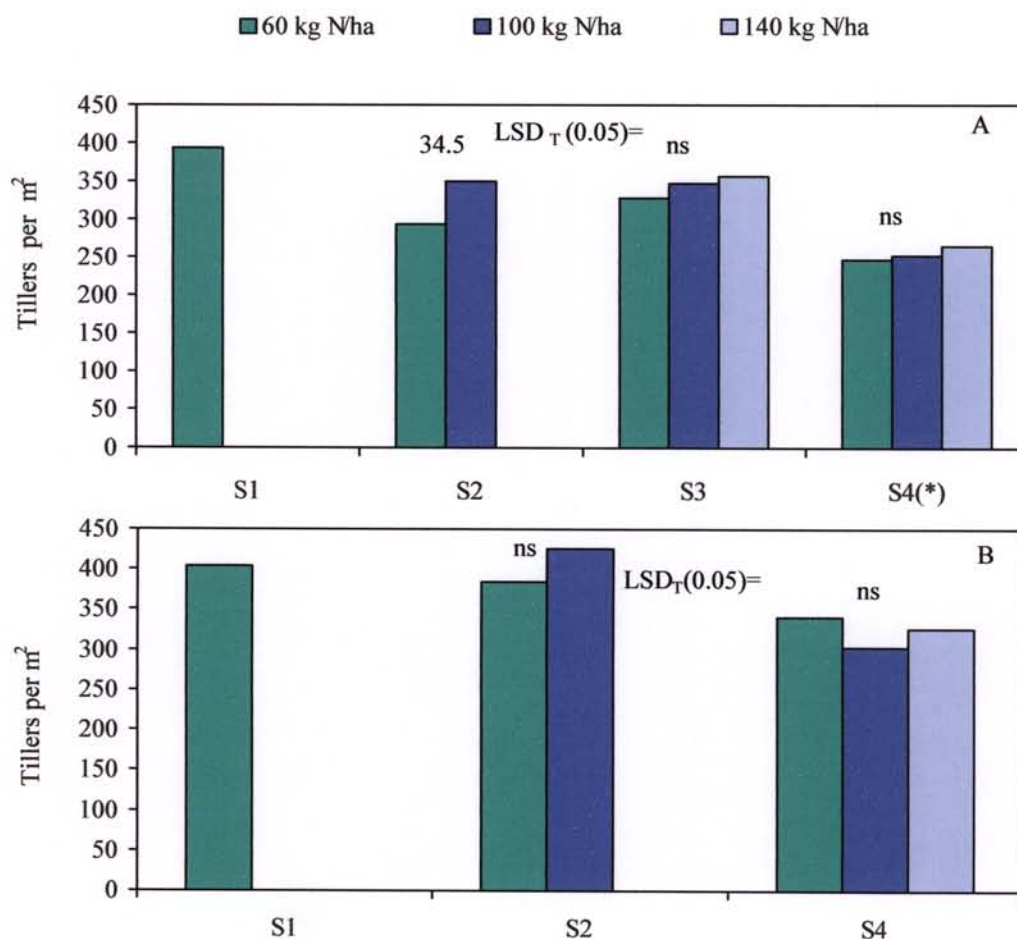


**Figure 5.2** Effect of wheat/wheat (WW) and wheat/lupin/wheat/canola (WLW C) crop rotations on A) tiller numbers per m<sup>2</sup> B) leaf area index C) total dry mass gm per m<sup>2</sup> of spring wheat at different growth stages (S<sub>1</sub> tillering, S<sub>2</sub> stem elongation, S<sub>3</sub> flage leaf, S<sub>4</sub> anthesis) during the 2000 growing seasons at Langgewens Experimental Farm  
(\*) Fertile tillers

In this study the effect of crop rotation on the studied wheat growth components was measured in 2000 growing season only. No significant differences were found at all sampling stages between different crop rotations, but in general crop rotation, (W/L/W/C) produced more tillers compared to monoculture wheat (W/W) (Fig.5.2a).

This also correlates with slightly higher mineral-N content found in the plots where a legume crop (lupin) formed part of the rotation system (Chapter 4).

Effect of nitrogen fertilisation on tillering is affected by the amount and distribution of the rainfall during the growing season as well as time of the applications (Galantini *et al.*, 2000). In this study the first top-dressing had been applied at tillering (after the S<sub>1</sub>-sampling), while the second top-dressing was applied during stem elongation (after S<sub>2</sub>-sampling).



**Figure 5.3** Effect of different rates of nitrogen fertilisation on spring wheat tiller numbers per m<sup>2</sup> at different growth stages (S<sub>1</sub> tillering, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm  
(\*) Fertile tillers



In the 2000 growing season nitrogen fertilisation had a significant effect on the tiller numbers especially at stem elongation ( $S_2$ ), which was sampled after the first top-dressing had been applied (Fig. 5.3a). From Figure 3.2 (Chapter 3) it is clear that it rained shortly after application the first top-dressing, which most probably resulted in good utilisation of nitrogen by the wheat plants.

The effect of the second nitrogen top-dressing, in contrast, was small because little rain fell after the application. Similar results had been obtained by Borghi (1999).

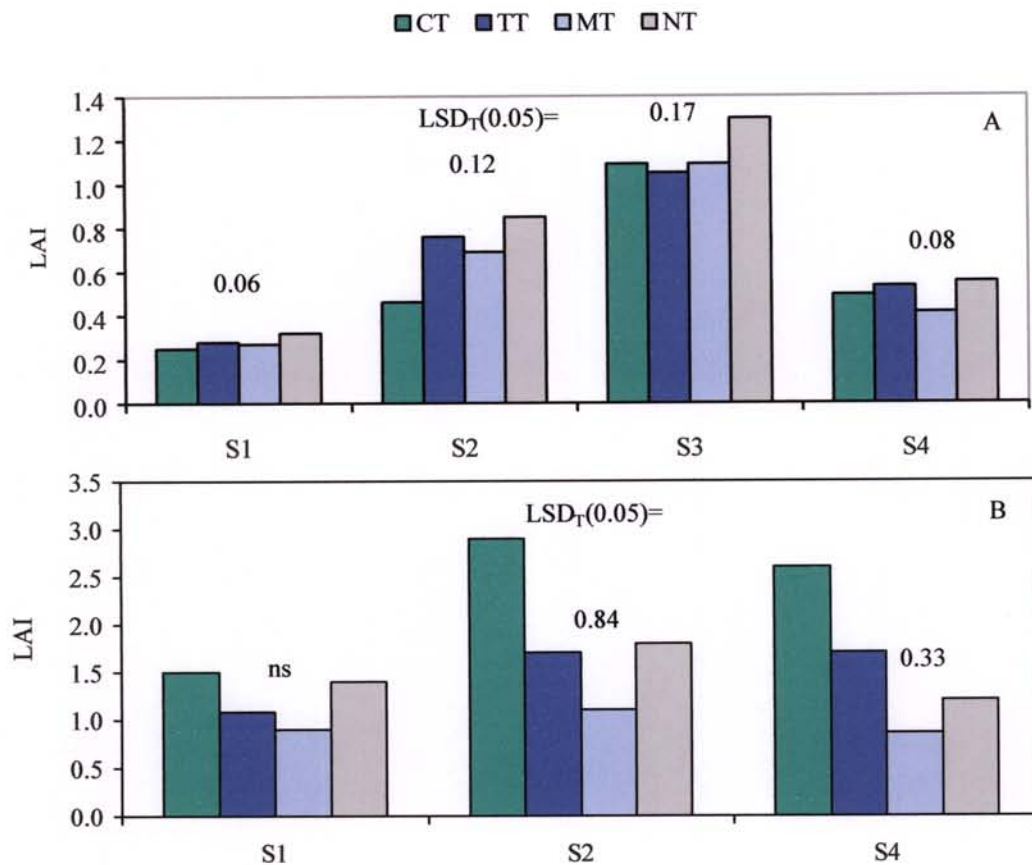
In the 2001 growing season tiller numbers per  $m^2$  was not significantly affected by the N top-dressing (100 and 140  $kg\ ha^{-1}$ ) (Figure 5.3b). This tendency may be attributed to the high rainfall after the N top-dressings had been applied (Fig.3.2), which might have caused some leaching.

### Leaf area index (LAI)

Leaf area index increased from tillering until the flag leaf stage where it reached the maximum and decreased toward anthesis. This coincide with the decrease in mineral-N content in the soil as mentioned earlier, which may resulte in accelerated the leaf senescences and ageing. In both growing season, LAI showed low values which varied between 0.2 to 1.3 in 2000 and from 0.9 to 2.8 in 2001. This might be related to the poor tillering capacity of this wheat cultivar as well as to the lower leaf numbers per plant. Leaf area index was significantly affected by different methods of tillage in both 2000 and 2001 growing seasons (Fig.5.4).

In the 2000 growing season, where the total rainfall was well below the long-term average, NT plots produced the largest leaf area index at all growth-sampling stages (Fig.5.4a). This might be related to better moisture conservation and better water use efficiency with NT. During the 2001 growing season, which was characterised by above long-term average rainfall, CT plots produced larger leaf area index compared to other tillage methods (Fig.5.4b).

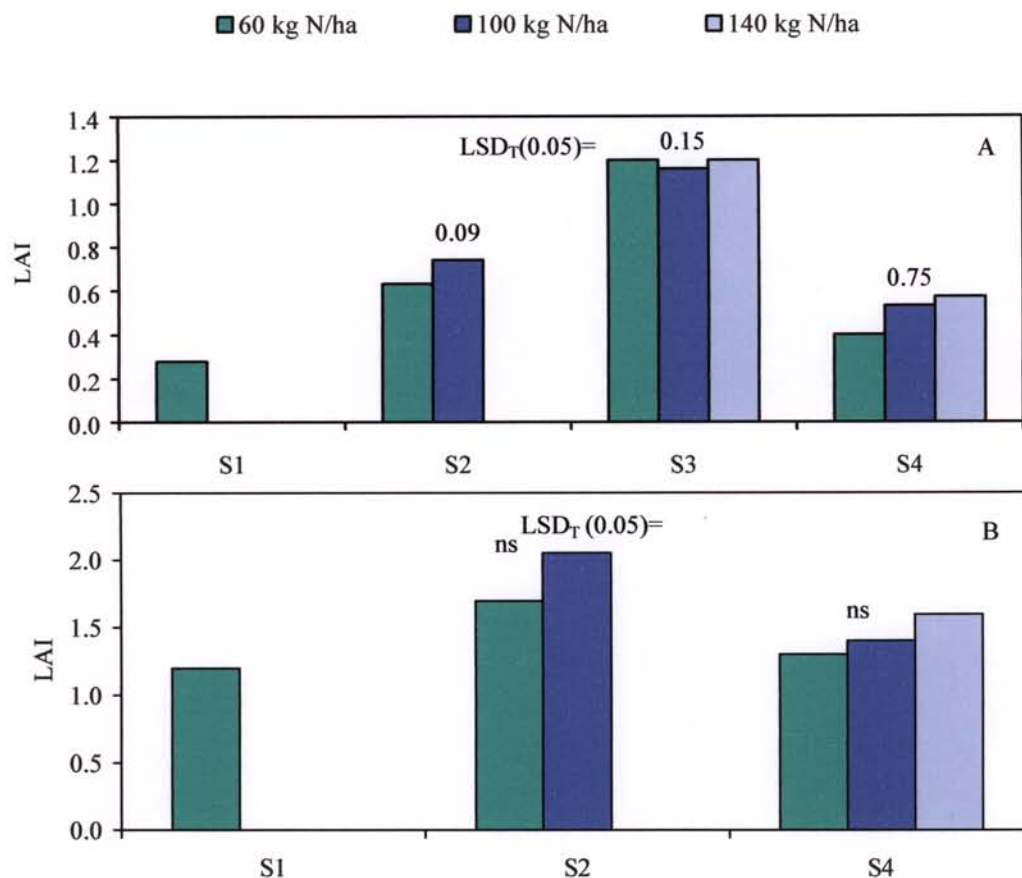
Significant differences for LAI due to crop rotation were only found at sampling ( $S_3$ ) at the flag leaf stage (Fig.5.2b), where crop rotation (wheat/lupin/ wheat/canola) plots produced larger LAI than monoculture (wheat/wheat) plots. The smaller than expected effect of crop rotation may be due to the fact that the legume crop (lupin) was grown once in a four year cycle only.



**Figure 5.4** Effect of conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no-tillage (NT) on leaf area index of spring wheat at different growth stages (S<sub>1</sub> tillering stage, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm

Nitrogen fertiliser application had a significant effect on LAI at all growth sampling stages during the 2000 growing season (Fig.5.5a). At stem elongation sampling stage (S<sub>2</sub>), which was sampled after the first top-dressing larger LAI was produced as a result of the top dressing. This may be due to the rainfall which occurred shortly after the nitrogen application, which resulted in good utilisation of nitrogen by wheat plants. At the flag leaf stage (S<sub>3</sub>), the second top-dressing had little effect because inadequate rain occurred after application, but at anthesis (S<sub>4</sub>) nitrogen top-dressing again caused an increase in LAI due to adequate amount of rainfall (Fig.3.2). In the 2001 growing season, LAI was not significantly affected by nitrogen top-dressing (100 & 140 kg ha<sup>-1</sup>), however, the second top-dressings produced a larger LAI than other treatments (Fig.5.5b). This result may be attributed to the high rainfall after the nitrogen top-dressings (Fig.3.2), which might have caused some leaching.



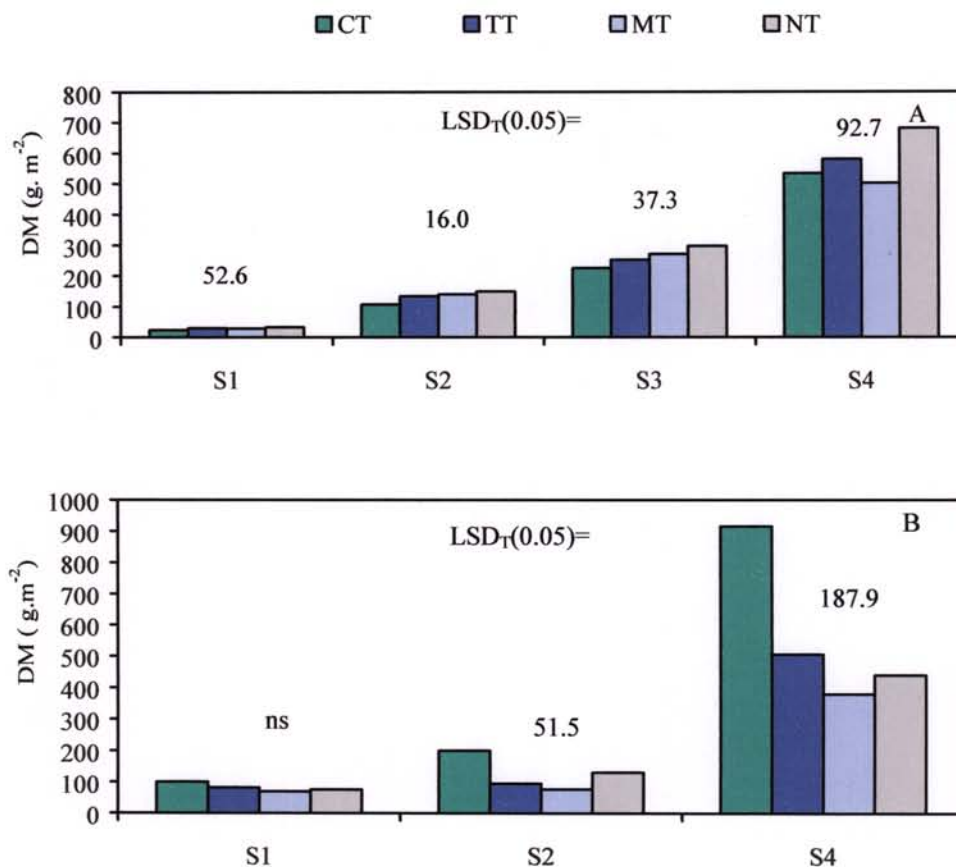


**Figure 5.5** Effect of different rates of nitrogen fertilisation on leaf area index of spring wheat at different growth stages (S<sub>1</sub> tillering stage, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm

#### Dry mass (DM)

The effect of tillage methods on dry mass (g. per m<sup>2</sup>) is presented in Figure 5.6. Dry mass (g. m<sup>-2</sup>) increased at successive growth stages sampled (S<sub>1</sub>-S<sub>4</sub>) in both years. During the 2000 growing season, significant differences were found between tillage methods at all growth stages sampled. No-till plots produced higher dry mass compared to other tillage methods (Fig.5.6a). During the 2001 growing season, significant differences were found in growth stages S<sub>2</sub> and S<sub>4</sub>. CT plots produced the highest dry mass and MT the lowest (Fig.5.6 b). Similar trends were observed for tiller numbers and leaf area index.

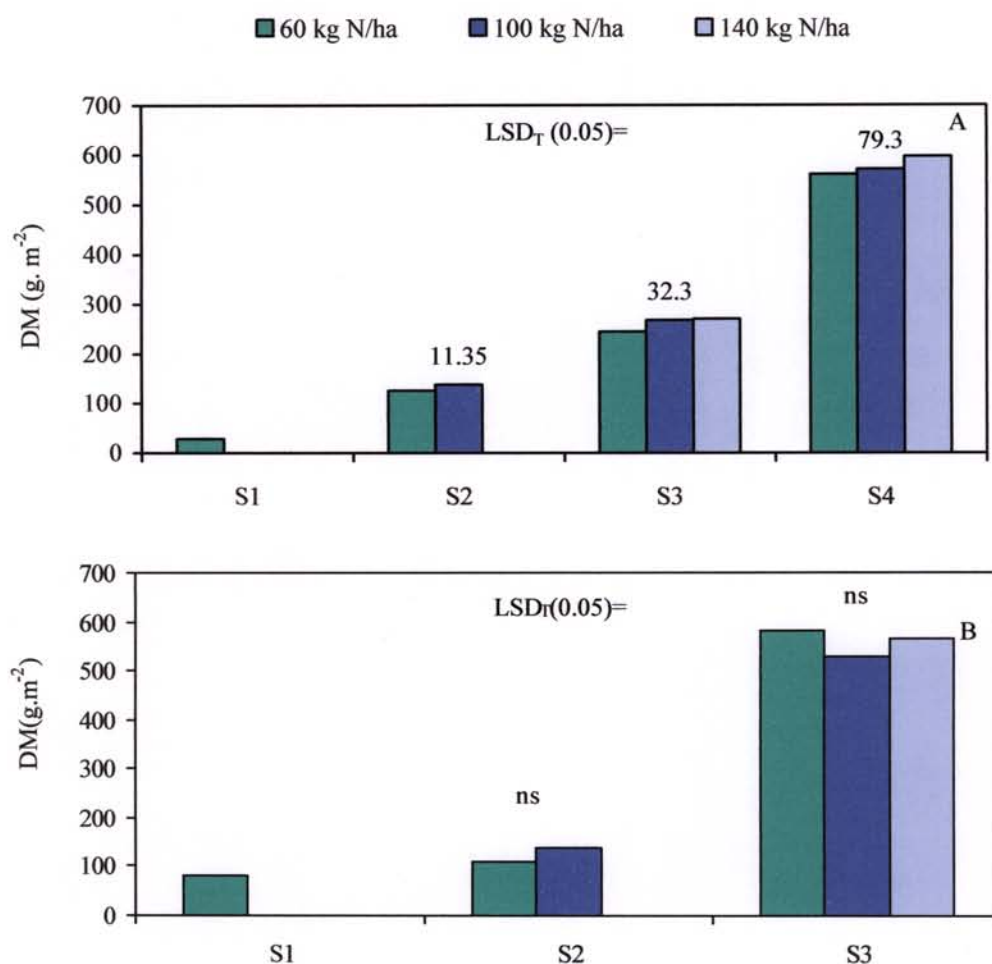
Although the effect of crop rotation on DM production was measured in 2000 only, significantly higher dry mass was produced on crop rotation plots compared to monoculture plots during most sampling stages (Fig.5.2c). This finding was in agreement with results of Galantini *et al.* (2000).



**Figure 5.6** Effect of conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no-tillage (NT) on dry mass, gm per m<sup>2</sup> of spring wheat at different growth stages (S<sub>1</sub> tillering stage, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm

In the 2000 growing season nitrogen fertilisation had a significant effect on the dry mass production at all sampling stages (Fig.5.7a). At stem elongation (S<sub>2</sub>), which was sampled after the first top-dressing, nitrogen top-dressing, increased the DM production significantly. At flag leaf stage (S<sub>3</sub>) and anthesis (S<sub>4</sub>), plots which received N-topdressing showed higher dry mass. This might be due to high rainfall during September and adequate time for the wheat plants to utilise the nitrogen (Fig.3.2). These results confirmed earlier result of McDonald (1992) who reported that dry biomass production increased with the addition of N fertilisers up to 100–150 kg ha<sup>-1</sup>.

During the 2001 growing season, dry mass production was not significantly affected by nitrogen top-dressing (100 & 140 kg ha<sup>-1</sup>) at all sampling stages (Fig.5.7b). High amounts of rainfall during this season probably caused some leaching. Similar trends were shown for tiller numbers and leaf area index and were in agreement with results of Garabet *et al.* (1998) as well as Galantini *et al.* (2000).



**Figure 5.7** Effect of different rates of nitrogen fertilisation on dry mass of spring wheat (g.m<sup>2</sup>) at different growth stages (S<sub>1</sub>tillering stage, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm

## Conclusion

Different methods of tillage showed a significant effect on spring wheat growth components. The effect however, varied largely between years due to annual variations in especially total and distribution of rainfall.

Although crop rotation had no significant effect on number of tillers per square metre, LAI was increased by crop rotation at the flag leaf stage.

The results of this study showed that although nitrogen application rates and time of application increased growth components, the effect varied between years due to climatic conditions such as total and distribution of rainfall.

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### **Effect of soil tillage, crop rotation and nitrogen application rates on N content of spring wheat (*Triticum aestivum*) in the Swartland wheat producing area of South Africa**

#### **Abstract**

Studies on total nitrogen content in spring wheat were conducted during the 2000 and 2001 growing seasons at Langgewens Experimental Farm in the Western Cape, wheat-producing area of the Republic of South Africa as part of a long-term tillage and crop rotation trial. Four tillage methods namely conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no-tillage (NT) were compared. Crop rotation systems used were continuous wheat (W/W) and wheat/lupin/wheat/canola (WLWC). Three rates of nitrogen fertiliser (60, 100 and 140 kg N ha<sup>-1</sup>) were applied. Wheat plants were sampled at tillering stage (S<sub>1</sub>), stem elongation (S<sub>2</sub>), flag leaf (S<sub>3</sub>) and anthesis (S<sub>4</sub>) during 2000. Due to bad weather conditions no sampling were done at the flag leaf stage during 2001.

The highest nitrogen contents (% of plant components) were found at tillering stage but decreased as the plant reached maturity. In this study nitrogen content expressed as g.plant<sup>-1</sup> and kg.ha<sup>-1</sup> was affected by different tillage methods in both seasons, but the response varied as a result of differences in rainfall during the growing seasons.

Significant differences for nitrogen content in the plant (g.plant<sup>-1</sup>) due to crop rotation were only found in samplings done at the tillering and flag leaf stages. At both stages plants from the crop rotation (wheat/lupin/wheat/canola) system resulted in significantly higher values compared to values found for plants from the monoculture (wheat/wheat) plots. A non-linear increase in the N content of the wheat crop with an increase in the N-application rate from 60 to 140 kg N ha<sup>-1</sup> indicated a decrease in N-use efficiency at higher application rates in both years.

**Key words:** Crop rotation, nitrogen content, N-fertiliser rates, tillage methods

#### **Introduction**

The growth and yield of grain crops are influenced substantially by the supply of N from the soil and fertiliser applications. The effect of N shortages are expressed through growth reduction factors, which limit leaf expansion, accelerate leaf senescence and modify the

rate of photosynthesis per unit leaf area or the light-use efficiency (Jamieson & Semenov, 2000).

During the vegetative phase of plants, N undergoes a continuous movement within the plant from roots to shoots and vice versa, but also between different tillers of the same plant (Borghi, 1999). Nitrogen remobilisation from senescent vegetative tissues to reproductive organs is the dominant process during grain filling and wheat has a great capacity to accumulate most of the N absorbed by the plant or present in its vegetative organs at this stage, in the grain (Borghi, 1999). Wetselaar & Farquhar (1980) found that N content in the foliage of winter wheat was at the highest level at flowering, and decreased between flowering and maturity. These authors concluded that in general nitrogen content in vegetative organs reached a maximum at anthesis. McGuire, Bryant & Denison (1998) reported that wheat plants absorbed only small portions of the total N after anthesis, but Guohua, Tang, Zhang & Zhang (2000) are of the opinion that although leaf nitrogen content decreased during the first two weeks of grain filling more nitrogen was absorbed after anthesis rather than before anthesis especially when additional nitrogen was applied at anthesis.

Factors influencing N uptake are growth stage, rooting density, soil temperature, soil water content, and application method of N fertilisers (Titulaer, 1999). Other factors like tillage methods and crop rotation may have an indirect effect on nitrogen uptake due to their effect on soil physical, chemical and biological conditions (López-Fando & Almendros, 1995; Hao *et al.*, 2000; Young & Ritz, 2000). Although no consistent effect of the tillage methods on nitrogen uptake was found in both well and poorly drained soils, less nitrogen in crops was obtained in undrained lands when no-tillage was used (Christian *et al.*, 1994). In cool climates very small differences in total nitrogen up-take by the plants were also found between tillage systems (Riley, 1998). Although the effect of reduced tillage on nutrient uptake was found to be inconsistent, reduced tillage resulted in slightly delayed plant dry matter development and slightly higher initial plant nitrogen concentrations compared with plough tillage in early stages, followed by an increase in total dry matter production without dilution of plant nitrogen concentration at later stages (Riley, 1998). Results of Power & Peterson (1998) showed that fallow tillage methods had no significant effect on nitrogen uptake in Argentina, but Falotico, Studdert & Echeverria (1999) found that total nitrogen accumulation in the plants were higher under conventional tillage than no-tillage. Differences were however reduced with high applications of nitrogen fertilisers. This result was attributed to the lower soil nitrogen supply under no-tillage as shown by lower estimated mineralisation of nitrogen during the crop-growing season. Soon, Clayton & Rice (2001) reported that more nitrogen was recovered from NT systems than from CT

systems as the wheat crop approached maturity under well drained sandy loam soil in Alberta. These results suggested that utilisation of N is less efficient in CT systems. Crop rotations with legumes improve soil physical, chemical and biological conditions, thereby enhancing nutrient availability and soil water content (Galantini *et al.*, 2000). Crops should therefore be rotated to ensure that residual nutrients left within the root zone by one crop are utilised by the following crop (Dala *et al.*, 1998; Galantini *et al.*, 2000; Prihar, Gajri, Benbi & Arora, 2000). Data of Strong *et al.* (1986) showed that the uptake of N by wheat was higher in the legume–wheat rotations compared to wheat-monoculture. Soon, Clayton & Rice (2001) showed that in comparison with monoculture, legume crops significantly increased N uptake by the following wheat crop mainly due to more mineralisation of N from organic matter and microbial biomass during crop growth. Heenan, McGhie & Collins (1998) on the other hand found that the incorporation of lupins in crop rotations had no consistent effect on nitrogen uptake by the following wheat crop. Annual addition of N fertiliser to continuously cropped wheat increased N uptake (Heenan, *et al.*, 1998), but Guohua *et al.* (2000) found that only cultivars with large spikes benefited from N applications at the late grain–filling stage. In Italy, Convertini *et al.* (1998) found that irrigation and nitrogen fertilisation had a significantly positive effect on total N content and N uptake in dry years while the effect of these treatments were small in the wet years.

The aim of this study was to determine the effect of tillage method, crop rotation and N-fertilisation on nitrogen content of spring wheat produced under a Mediterranean-type climate in the Republic of South Africa.

## **Material and methods**

Studies on total nitrogen content in a spring wheat crop were conducted during 2000 and 2001 growing seasons as part of a long-term tillage and crop rotation trial. Although the tillage treatments tested were used since 1976, present crop rotations and nitrogen application rates were only applied since 1990. Detailed descriptions of the locality, climate, treatments, experimental layout and procedures as well as data analyses are presented in Chapter 3.

### **Plant samplings**

Wheat plants were sampled at tillering stage (S<sub>1</sub>), stem elongation (S<sub>2</sub>), flag leaf (S<sub>3</sub>) and anthesis (S<sub>4</sub>) during 2000. Due to bad weather conditions no sampling was done at the

flag leaf stage during 2001. Ten plants were taken at random from each sub-plot, the plants were separated in to leaves, stems and spikes, and dried at 80 °C for 48 hours. Afterwards leaves, stems and spike samples were milled and the nitrogen percentage was determined by Near Infra-Red Spectroscopy (Technikon Infraalyzer 400). Total nitrogen in the plant ( $\text{g.plant}^{-1}$ ) was calculated by multiplying leaf N% by the dry weight of different components and then adding all together. Total nitrogen ( $\text{kg.ha}^{-1}$ ) was calculated by taking the number of plants per  $\text{m}^2$  (Chapter 5) into account.

## Results and discussion

### Nitrogen content (%) of plant components

Nitrogen content in the different components (leaves, stems and spikes) of the wheat plants decreased with time during both growing seasons (Table 6.1). The highest nitrogen content, expressed as a percentage of dry mass was found in the leaves at tillering stage in both growing seasons namely 4.89 % and 5% in the 2000 and 2001 respectively and decreased in all components as the plants reached maturity.

**Table 6.1** Mean nitrogen percentage in the leaf, stem and spike of spring wheat for different plant sampling during 2000 and 2001 growing season at Langgewens Research Farm.

Year	Plant sampling	N % in the leaves	N % in the stem	N % in the spike
2000	S <sub>1</sub>	4.89	*	*
	S <sub>2</sub>	4.47	*	*
	S <sub>3</sub>	3.91	4.68	*
	S <sub>4</sub>	3.46	4.12	2.16
Mean		4.18	4.4	2.16
2001	S <sub>1</sub>	5	*	*
	S <sub>2</sub>	4.7	4.1	*
	S <sub>4</sub>	3.99	3.18	2.02
Mean		4.56	3.64	2.02

S<sub>1</sub> at tillering stage, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis

\* Stem and spikes not developed yet

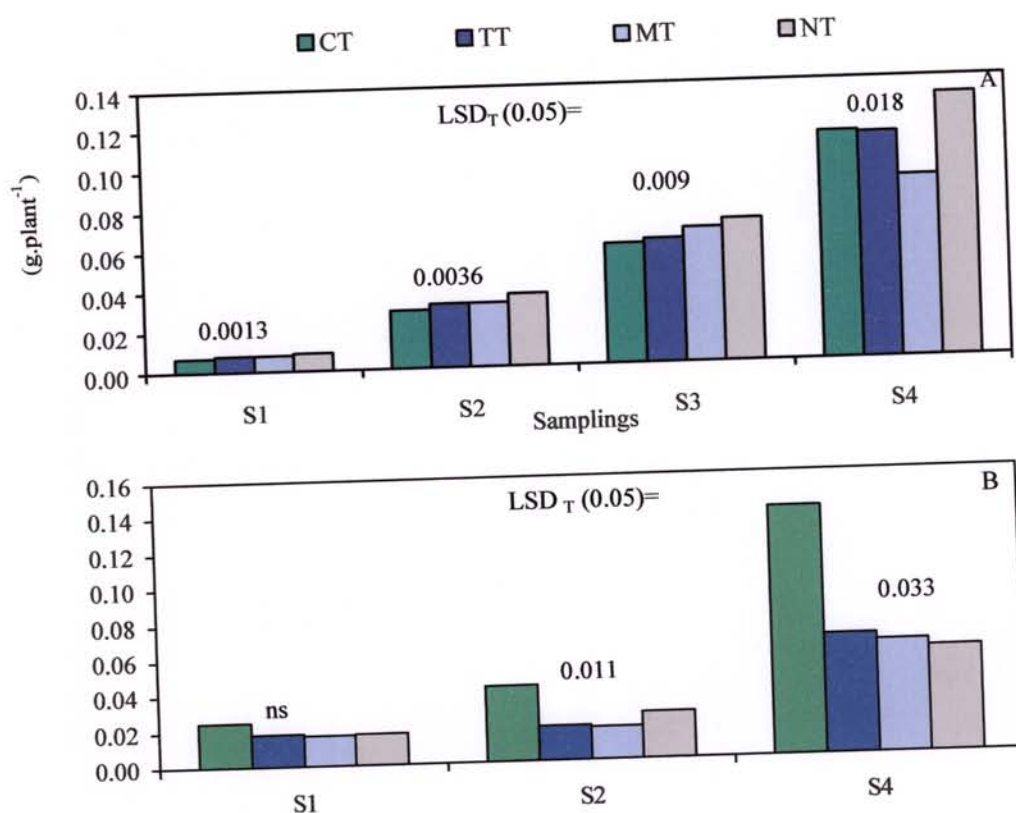
Similar results were reported by (Power & Peterson, 1998; Rostami & Giriaei, 1998). Decreased concentrations may be due to reduced up-take, differences in allocation between plant components or most probably due to rapid increases in dry mass. Treatment effects on

dry mass accumulation therefore also have an effect on N concentration. Treatments effect therefore became very complicated and difficult to illustrate. Because of these complicating factors and because the nitrogen content decreased in all components as the plants reached maturity during both years it was decided to use only the total nitrogen content in the plants (expressed as gram per plant and kg per hectare) for further discussions.

Effect of tillage methods on nitrogen content ( $\text{g.plant}^{-1}$  and  $\text{kg.ha}^{-1}$ )

Tillage methods have an indirect effect on nitrogen content in the plants due to its effect on soil physical, chemical and biological conditions (López-Fando & Almendros, 1995; Hao *et al.*, 2000; Young & Ritz, 2000).

In this study nitrogen content ( $\text{g.plant}^{-1}$ ) was affected by different tillage methods in both growing seasons. During the 2000 growing season, where the total rainfall was well below the long-term average, a significant difference was found between tillage methods with the



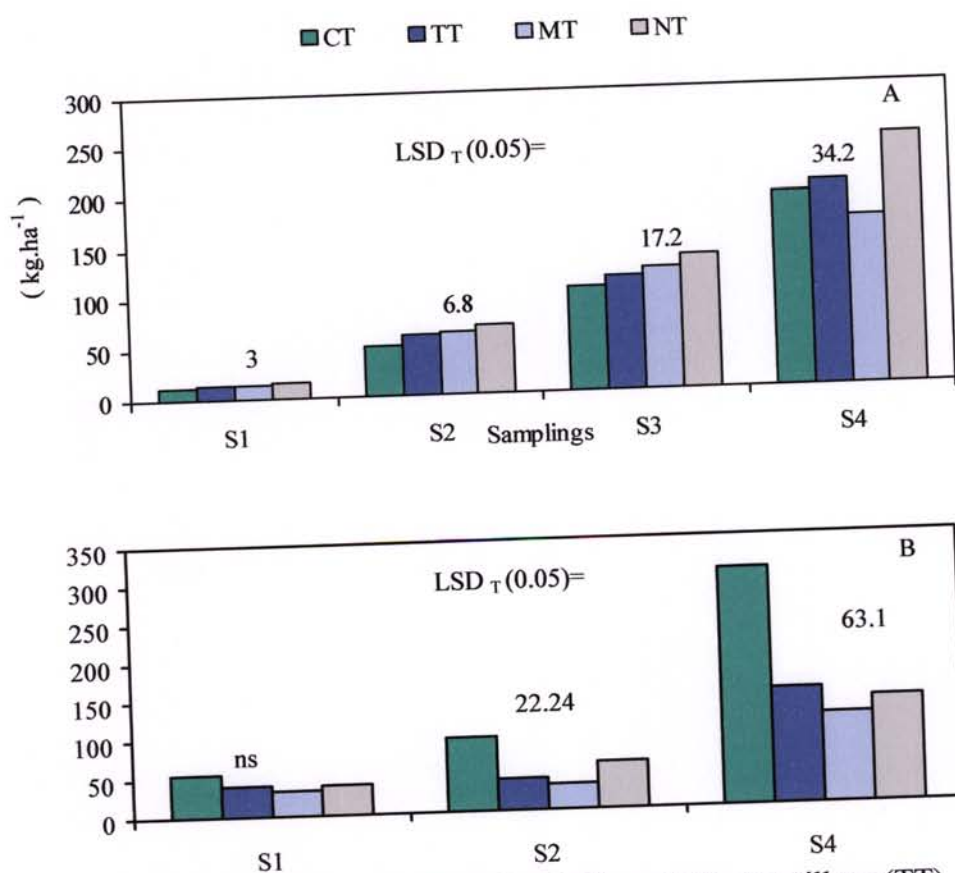
**Figure 6.1** Effect of conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no tillage (NT) on total nitrogen content in the wheat ( $\text{g.plant}^{-1}$ ) at different growth stages (S<sub>1</sub> tillering, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm



highest contents in plants from NT plots during all sampling dates (Fig.6.1a).

Conventional tillage (CT) on the other hand showed the lowest values during most of the sampling stages. Lawrence *et al.* (1994), Lafond *et al.* (1996) & Titulaer (1999) reported similar results, which they attributed to the better soil water conservation and water use efficiency for no-tillage compared to other tillage methods in years with below average rainfall. During the 2001 growing season, which was characterised by above average precipitation, highest values were found with CT and the lowest with NT (Fig.6.1 b). These results supported the views of the above-mentioned researchers with regard to the effect of different tillage methods in wet and dry years.

Total nitrogen content in the wheat crop expressed as  $\text{kg.ha}^{-1}$  showed the same trend as for  $\text{g.plant}^{-1}$  in both years (Fig.6.2) and increased for all plots with successive samplings as the crop reached maturity. These results confirm earlier results of Wetselaar & Farquhar (1980) and McGuire *et al.* (1998). The above-mentioned differences in N content in the wheat plants ( $\text{g.plant}^{-1}$  &  $\text{kg.ha}^{-1}$ ) found with different methods of tillage indicated that N uptake or use efficiency was effected by different methods of tillage.



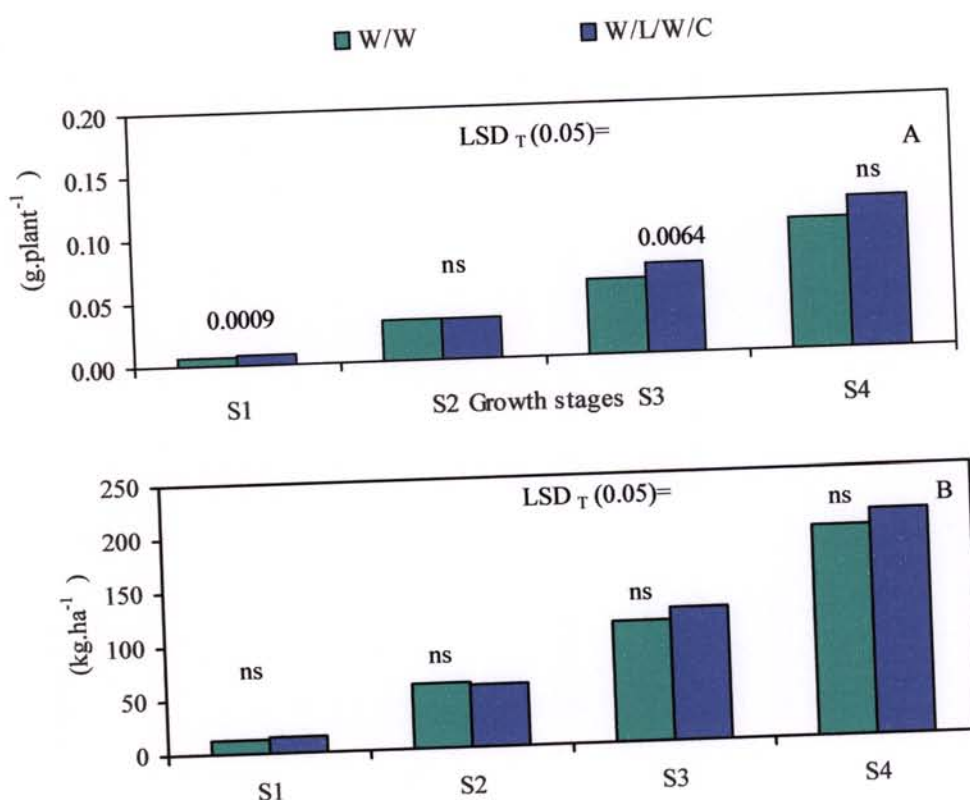
**Figure 6.2** Effect of conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no tillage (NT) on total nitrogen content in the wheat ( $\text{kg.ha}^{-1}$ ) at different growth stages (S<sub>1</sub> tillering, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) in the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm



## Effect of crop rotations on total nitrogen content ( $\text{g.plant}^{-1}$ and $\text{kg.ha}^{-1}$ )

Crop rotations which included legume species may have a direct effect on nitrogen content of succeeding crops due to N-fixing by the legumes, or have an indirect effect due to the improvement of soil physical, chemical and biological conditions (Galantini *et al.*, 2000 & Soon *et al.*, 2001).

In this study significant differences for total nitrogen content in the plant ( $\text{g.plant}^{-1}$ ) due to crop rotation, were only shown in samplings done at the tillering and flag leaf stages. At both stages plants from the crop rotation system (WLWC) resulted in significantly higher values compare to values found for plants from the monoculture (WW) plots (Fig.6.3a).



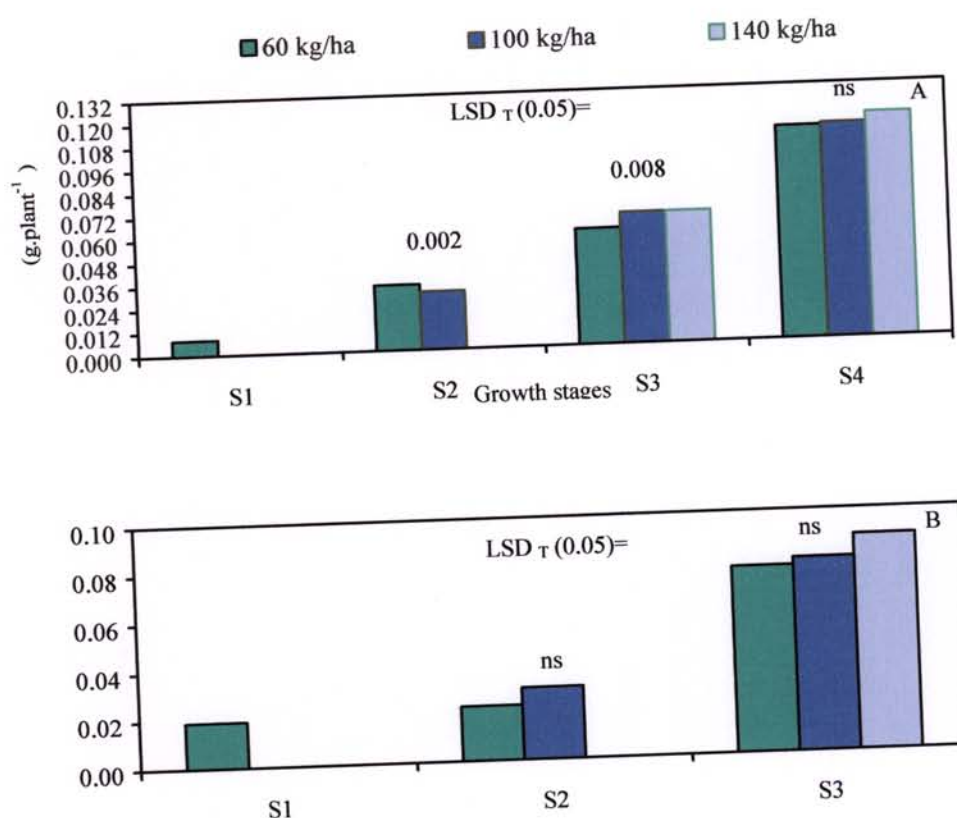
**Figure 6.3** Effect of crop rotation wheat/wheat (WW) and wheat/lupine/canola (WLWC) on total nitrogen content in wheat A) ( $\text{g.plant}^{-1}$ ) and B) ( $\text{kg.ha}^{-1}$ ) at different growth stages (S<sub>1</sub> tillering, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) during the 2000 growing season at Langgewens Experimental Farm

Total nitrogen content in the crop ( $\text{kg.ha}^{-1}$ ) however did not differ significantly, but in general nitrogen content in wheat plants from the (WLWC) rotation was found to be slightly higher compared to the wheat-monoculture (Fig.6.3b). These findings supported the results of Strong *et al.* (1986) and may indicate that the beneficial effect of the crop rotation in this study may primarily be attributed to the effect of crop rotation on growth

factors like diseases, weeds and soil structure and not N-fixation. As already mentioned, Chapter 4 crop rotation did not have a large effect on the mineral-N content of the soil in this study. These absences of clear differences in mineral-N content of the soil are most probably due to the fact that in this study legumes were planted only once in a four-year cycle.

Effect of nitrogen application rate on total nitrogen content ( $\text{g.plant}^{-1}$  and  $\text{kg.ha}^{-1}$ )

Effect of different rates of nitrogen fertilisation on total nitrogen content in wheat ( $\text{g.plant}^{-1}$  and  $\text{kg.ha}^{-1}$ ) are presented in (Fig's. 6.4 & 6.5) respectively. Total nitrogen content in the plant tended to be higher during the 2000-growing season compared to 2001.



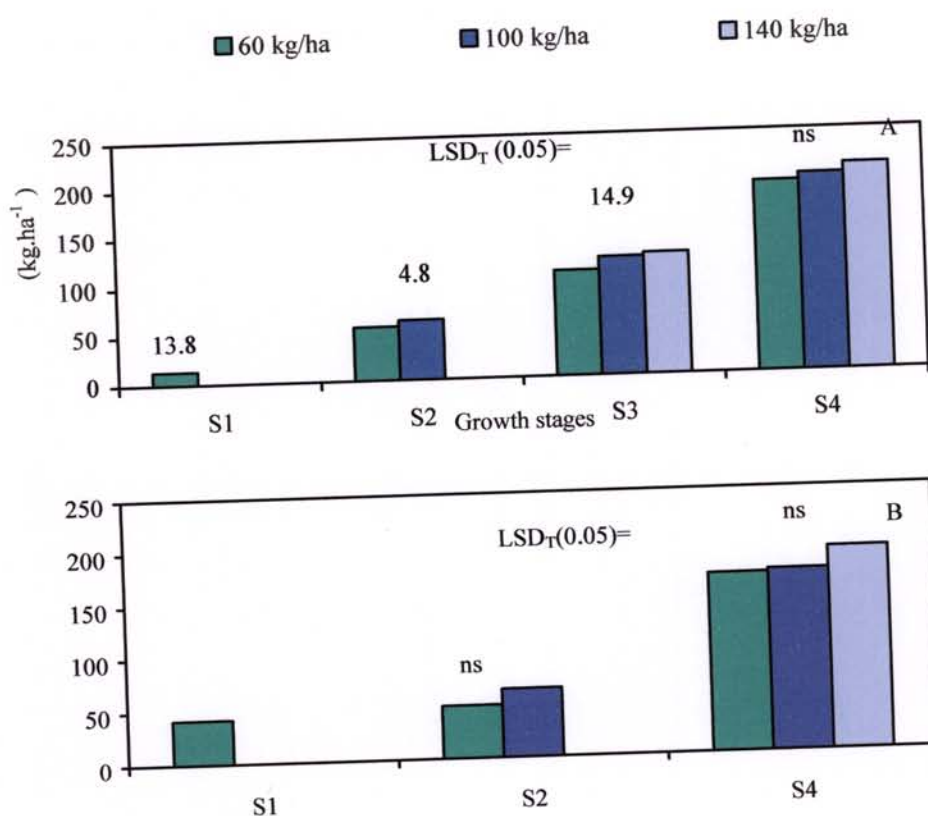
**Figure 6.4** Effect of different rates of nitrogen fertilisation on total nitrogen content in wheat ( $\text{g.plant}^{-1}$ ) at different growth stages ( $S_1$  tillering,  $S_2$  stem elongation,  $S_3$  flag leaf,  $S_4$  anthesis) in the A) 2000 and B) 2001 growing seasons at Langgewens Experimenta Farm.

This was probably due to the high mineral-N content in the soil (Chapter 4) or less leaching during the 2000 season. During 2000, application of different rates of nitrogen fertiliser affected total nitrogen content in wheat plants only during samplings at stem elongation and flag leaf stages (Fig. 6.4 a).



At stem elongation plants which received only N at planting ( $60 \text{ kg N ha}^{-1}$ ) out yielded plants that received a top-dressing at the tillering ( $100 \text{ kg N ha}^{-1}$ ) with regard to the total nitrogen content per plant. This was somewhat unexpected and may be due to a sampling error or due to the very dry conditions experienced during the early part of the 2000-growing season, which might have limited the uptake of the N applied as a top-dressing. Samplings done at the flag leaf stage after the soil moisture conditions had improved, resulted in significantly less nitrogen in plants from the  $60 \text{ kg N ha}^{-1}$  treatment compared to the 100 and  $140 \text{ kg N ha}^{-1}$  treatments, but no differences were shown between the latter. At anthesis, however, highest values were found in plants from the  $140 \text{ kg N ha}^{-1}$  treatment (Fig. 6.4 a).

During 2001, nitrogen treatments which received top-dressings at the tillering ( $100 \text{ kg ha}^{-1}$ ) and tillering plus stem elongation stages ( $140 \text{ kg ha}^{-1}$ ) resulted in more nitrogen in the wheat plants compared to  $60 \text{ kg ha}^{-1}$  treatment which received nitrogen at seeding only (Fig.6.4b). Differences were however not significant at the  $P=0.05$  level.



**Figure 6.5** Effect of different rates of nitrogen fertilisation on total nitrogen content in the wheat ( $\text{kg ha}^{-1}$ ) at afferent growth stages (S<sub>1</sub> tillering, S<sub>2</sub> stem elongation, S<sub>3</sub> flag leaf, S<sub>4</sub> anthesis) in the A) 2000 and B) 2001 at Langgewens Experimental Farm

Although plant growth and therefore N-uptake might have benefited from the higher rainfall during the growing season, higher losses due to leaching could have contributed to the somewhat confined crop responses during 2001.

Similar trends were recorded for total nitrogen content in the wheat ( $\text{kg} \cdot \text{ha}^{-1}$ ) in both growing seasons.

In 2000, total nitrogen content in the wheat crop at anthesis were 196, 203 and  $212 \text{ kg ha}^{-1}$  for the 60, 100 and  $140 \text{ kg N ha}^{-1}$  treatments respectively, while total nitrogen content in the wheat crop at anthesis in the 2001 growing season was found to be 169, 171 and  $191 \text{ kg ha}^{-1}$  for the 60, 100,  $140 \text{ kg N ha}^{-1}$  treatments respectively (Fig. 6.5). These results clearly showed a non-linear increase in the N content of the wheat crop with an increase in the N-application rate from 60 to  $140 \text{ kg N ha}^{-1}$  indicating a decrease in N-use efficiency at higher application rates in both years. Values of 196 and  $169 \text{ kg N ha}^{-1}$  in the wheat crop for the  $60 \text{ kg N ha}^{-1}$  treatment also illustrated the importance of the contribution made by N-mineralisation to the N supply of these crops and the extend of annual differences that may occur due to the variation in annual climatic conditions. Soil measurements of N-mineralisation or predictions of this process based on soil and climatic conditions may therefore become very important in improving future fertilisation programmes.

## Conclusion

Differences in nitrogen content of the spring wheat were found between different tillage systems, were largely affected by the climatic conditions especially total and distribution of rainfall. In low rainfall years ( $\pm 250 \text{ mm}$  during the growth period), highest nitrogen content was obtained with no-tillage. In high rainfall years ( $\pm 450 \text{ mm}$  during the growth period), on the other hand, highest nitrogen content was obtained with conventional mouldboard tillage.

Although the use of crop rotations which include legumes may improve the nitrogen content of the spring wheat, results of this study showed that the beneficial effect will be relative small, if legumes were planted only once in a four year cycle.

The response to N-fertiliser rates was largely affected by rainfall during the growth period and N-mineralisation. In order to improve fertilisation programmes under Mediterranean environments, soil measurements of N-mineralisation or predictions of this process based on soil and climatic conditions as well as the effect of rainfall on N-leaching and up-take may become necessary.

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### Effect of soil tillage, crop rotation and nitrogen application rates on grain yield of spring wheat (*Triticum aestivum* L.) in the Swartland wheat producing area of South Africa

#### Abstract

Studies on spring wheat yield components were conducted during the 2000 and 2001 growing seasons only, while grain yield responses to tillage, crop rotation and N-rates during these years were compared to yields for the period 1992-1998 at Langgewens Experimental Farm in the Western Cape as part of a long-term tillage and crop rotation trial. Four tillage methods were used, namely conventional tillage (CT), tine tillage (TT), minimum tillage (MT), and no-tillage (NT). Crop rotation systems used were continuous wheat (WW) and wheat/lupin/wheat/canola (WLWC). Three rates of N-fertilisers (60, 100 and 140 kg N ha<sup>-1</sup>) were applied.

Tillage methods had a significant effect on the number of spikes per square metre, spikelets per spike and number of kernels per spike in both the 2000 and 2001 growing seasons. Thousand kernel mass were not significantly affected by different tillage methods in both seasons. Mean grain yield for the period 1992-1998 did not differ significantly as a result of different tillage methods, but differences due to tillage methods were found in both the 2000 and 2001 growing seasons.

Crop rotation had no significant effect on all the abovementioned yield components. Significantly higher yields for the period 1992-1998 were produced when wheat was rotated with lupins and canola (WLWC) compared to monoculture wheat (WW).

Application of different rates of nitrogen had no significant effect on the number of spikes per square metre, number of spikelets per spike and 1000-kernel mass in both growing seasons. While higher rates of nitrogen increased the number of kernels per spike and grain yield in the 2001 growing season, no significant differences were observed between different N rates in the dry season (2000) and the results even indicated a decreased in yield with increasing nitrogen rates in this year. Significant tillage x crop rotation and tillage x nitrogen interaction for the mean grain yield during the 1992-1998 period, however, indicated that yield responses to tillage were related to soil conditions.

**Keywords:** Crop rotation, grain yield, tillage methods, yield components.

## Introduction

The majority of spring wheat (*Triticum aestivum* L.) produced in South Africa is grown under rain-fed Mediterranean-type climate, which is characterised by wide oscillation in the annual rainfall. López-Bellido *et al.*, (1996), who studied long-term effects of tillage, crop rotation, and nitrogen fertiliser on wheat yield planted under rain-fed Mediterranean conditions, found that differences in rainfall during the growing season had a marked effect on wheat yield and responses to the above mentioned production techniques. For example in dry years, higher yields were produced under a no-tillage system compared to conventional tillage, but this was not the case in wet years. Results of many other researchers also showed that no-tillage out yielded other tillage systems especially in years with below normal precipitation (Lawrence *et al.*, 1994; Martinez, O'Leary & Connor, 1995; Pratley, 1995; Lafond *et al.*, 1996; Strong *et al.*, 1996; Halvorson, Black, Krupinsky & Merrill, 1999; Du-Bing *et al.*, 2000). Kirkegaard (1995) on the other hand, showed that the overall effect of tillage systems on wheat yields are usually small. López-Fando & Almendros (1995) as well as Unger (1994) therefore suggested that no-tillage had little or no effect on crop parameters in semi-arid environments. Results of Agenbag & Maree (1988 & 1991) in contrast, showed that the yield of spring wheat grown in shallow, stony soil in Mediterranean-type climates is reduced if no-tillage is used. This was attributed to high soil cone resistance which reduced rooting ability, lower mineral nitrogen content in the soil at seeding as well as lower plant densities.

Under cool, humid climatic conditions Carter (1994) found that grain yield and yield components differed significantly annually, but not consistently due to any tillage treatment. In general grain mass tended to be higher after the chisel ploughing compared to mouldboard tillage.

The positive effect of crop rotation on wheat yield is well documented and has been long known. Crop rotation increased yield relative to monocultures (Heenan, Taylor, Cullis & Lill 1994; Kirkegaard, 1995; López-Fando & Almendros, 1995; Grace, Oades, Keith, & Hancock, 1995; Dala *et al.*, 1998; Galantini *et al.*, 2000; Weisz, Crozier & Heiniger, 2001), due to the increased amount of residual mineral-N in the soil and better water use efficiency. Continuously cropped wheat, fertilised with nitrogen, usually produced a lower yield than those followed a lupin crop (Heenan, McGhie & Collins, 1998). The same applies for wheat after field peas, but results of Arshad, Soon & Azooz (2002) showed little advantages due to the inclusion of canola crop in northern Alberta. Higher yields obtained in the wheat/lupin rotation were attributed to a higher number of spikes per unit

area (Heenen *et al.*, 1998). However, the effect of the previous crop on wheat productivity depends on seasonal rainfall during the wheat year as well as during the preceding legume year.

Increasing N rates increased grain production, but yield response to N-rate varied between years (Halvorson *et al.*, 1999). Under Mediterranean-type climates, however, wheat usually did not respond to N fertiliser when rainfall was less than 450 mm during the growing season (López-Bellido *et al.*, 1996), but increased with increasing rates up to 100 kg ha<sup>-1</sup> in years with high rainfall (López-Bellido & López-Bellido, 2001). Responses to N-rate also depend on mineral N content of the soil with high N-contents, response are usually small or even absent (López-Bellido & López-Bellido, 2001). Frederick & Camberato (1995a & 1995b) found that the application of below the recommended rates of nitrogen resulted in fewer kernels per m<sup>2</sup> at maturity, which proved to be the best indicator of wheat response to N. Yield components are affected not only by the rate of N fertilisation, but also by the timing of the application to prevent nitrogen deficiencies at critical stages (Borghi, 1999). Nitrogen deficiency at tillering for instance decreased the number of ear bearing tillers, spikelets per spike and kernels per spike. Deficiencies prior to anthesis also caused reductions in kernel number, due to less kernel per spikelets (Mainard, Jeuffroy & Robin (1999).

The aim of this study was to determine the grain yield and yield components response to different tillage methods; crop rotations and rates of nitrogen fertilisation in spring wheat produced under a Mediterranean-type climate in the Republic of South Africa.

## Materials and methods

Studies on spring wheat yield components (spike per m<sup>2</sup>, spikelets per spike, kernels per spike and 1000 kernel mass) were conducted during the 2000 and 2001 growing seasons as part of a long-term tillage and crop rotation trial. Grain yields obtained during these seasons were compared to the mean yields obtained during the 1992, 1994, 1996 and 1998 seasons. Although the tillage treatments were tested since 1976, present crop rotations and nitrogen application rates were only applied since 1990. Description of locality, climate, experimental layout and treatments as well as data analysis are presented in Chapter 3.

### Plant samplings

Spike numbers per square metre for different tillage methods, different rates of nitrogen and crop rotation (2000 only) treatments were counted at harvesting in 2000 and at physiological maturity in 2001. Three randomised chosen samples of 0.5 m<sup>2</sup> were counted



per sub-plot. Three samples of 25 spikes were harvested from each sub-plot to determine the spikelets per spike, kernels per spike and finally the 1000 kernel mass. Bulk harvesting per sub-plot to determine grain yield was done by a combine harvester. Representative seed samples of approximately 2 kg each were collected from the final yield of each sub-plot to determine 1000 kernel mass in the 2001.

## Results and discussions

### Yield components

#### Spikes per square metre (spikes m<sup>-2</sup>)

Number of spikes per square metre ranged from 275 to 314 for the 2000 growing season and from 240 to 305 for the 2001 season. Tillage methods had a significant effect on the number of spikes per square meter in both 2000 and 2001 growing seasons (Table 7.1).

**Table 7.1** Effect of tillage methods, crop rotation and different rates of nitrogen fertiliser on the number of spikes per m<sup>2</sup> of spring wheat at Langgewens Experimental Farm

Tillage methods	2000 season	2001 season
CT	278	305
TT	299	286
MT	314	264
NT	302	243
Mean	298	275
LSD <sub>T</sub> (0.05)	25.9	54.8
Crop rotation		
WW	298	-
WLWC	299	-
Mean	199	-
LSD <sub>T</sub> (0.05)	ns	-
Nitrogen fertiliser rates		
60 kg N ha <sup>-1</sup>	295	268
100 kg N ha <sup>-1</sup>	297	272
140 kg N ha <sup>-1</sup>	303	283
Mean	298	274
LSD <sub>T</sub> (0.05)	ns	ns

CT conventional tillage, TT tine tillage, MT minimum tillage, NT no-tillage

WW monoculture, WLWC wheat/lupin/wheat/canola

- No crop rotation in 2001

During the 2000 season, which was characterised by dry conditions, minimum tillage (MT) plots produced more spikes per square metre than other tillage plots, while conventional tillage (CT) plots produced the least. In contrast to this, CT plots produced the highest number of spikes per square metre in the 2001 season, while NT plots produced the least (Table 7.1). Similar trends were shown with regard to the number of tillers per square metre (Chapter 5). Since plant numbers did not differ (Chapter 5), these results must be due

to tillage-induced differences in soil conditions during the early part of the growth period when tillering took place. Although soil moisture content was not measured, these results were probable due to the well-proven (Lawrence *et al.*, 1994; Martinez *et al.*, 1995; Pratley 1995; Lafond *et al.*, 1996; Strong *et al.*, 1996; Halvorson *et al.*, 1999; Du-Bing *et al.*, 2000) moisture conserving abilities of no-tillage, because rainfall during the months of April, May and June 2000, were shown to be well below long term average (Chapter 3). Earlier results of this research (Agenbag, 1987) showed that the number of stress days during the growth period could be reduced if less intensive methods of tillage (MT, NT) are used.

In this study the effect of crop rotation on wheat yield and yield components was measured during the 2000-growing season only. Crop rotation did not significantly affect the number of spikes per square metre, which may be explained by the cultivation of a legume crop (lupins) only once every four years.

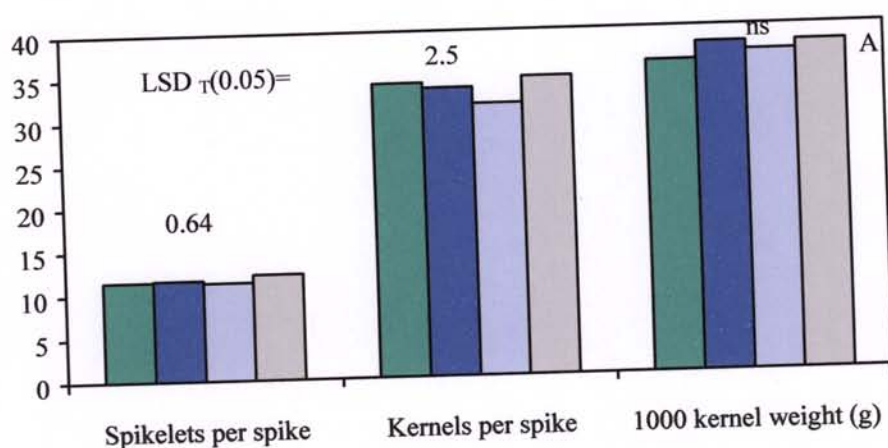
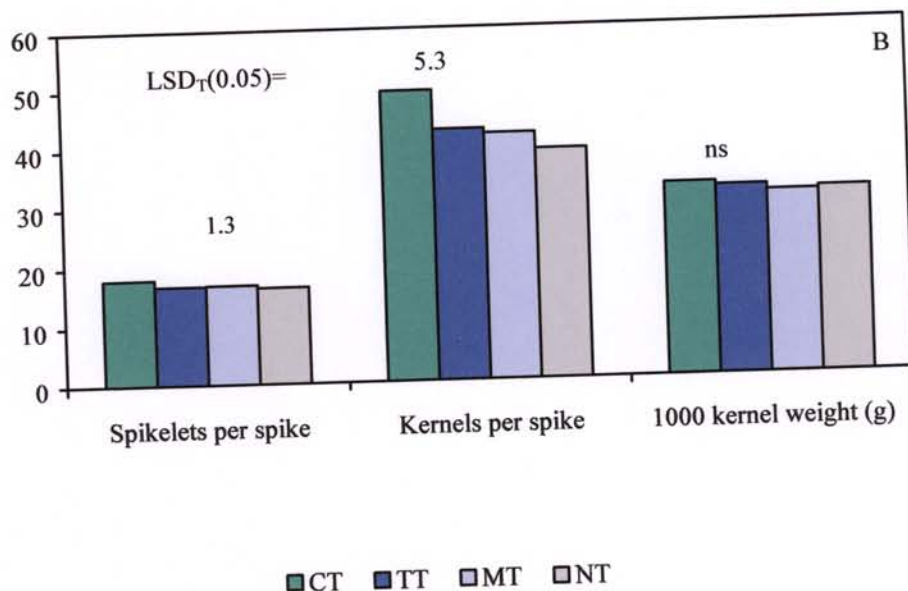
Application of different rates of nitrogen fertilisers also had no significant effect on the number of spikes per square metre in both growing seasons (Table 7.1) indicating that the N-application of 60 kg N ha<sup>-1</sup> at planting was sufficient to prevent any N-deficiencies during the early growth stages.

#### Number of spikelets per spike

Number of spikelets per spike varied from 11.3 to 12.2 for 2000 and from 16.4 to 18 for 2001. This component was significantly affected by the different tillage methods used in both 2000 and 2001 growing seasons (Fig.7.1). Results showed almost the same trend as for spikes per square metre, and probably for the same reason as spikelets per spike developed more or less simultaneously with tillering (Evans, Wardlaw & Fisher, 1975). In 2000 the highest number of spikelets per spike was produced by plants on NT plots, while plants on CT plots produced the least. During the 2001 growing season, which was characterised by wet conditions, CT resulted in the highest number of spikelets per spike, while NT resulted in the least (Fig.7.1). No significant effects were found for either crop rotation (Fig.7.2), or the application of different rates of nitrogen fertiliser (Fig.7.3).

#### Number of kernels per spike

Number of kernels per spike ranged from (31 to 34.5) and from (38.9 to 49) during the 2000 and 2001 growing seasons respectively. Results for different tillage methods and crop rotations were similar to those found for number of spikelets per spike (Fig. 7.1).

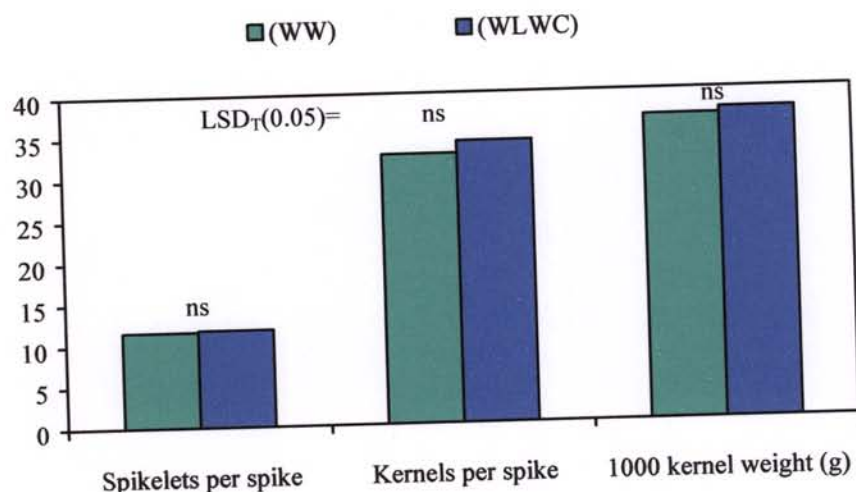


**Figure 7.1** Effect of conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no-tillage (NT) on spikelets per spike, seed per spikelet and 1000 kernel weight (g) of spring wheat during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm

Different rates of nitrogen fertiliser had a significant effect on the number of kernels per spike in the 2001-growing season only (Fig.7.3), where higher rates increased the number of kernels per spike. These results confirmed those of Frederick & Camberato (1995a & 1995b) and Mainard, Jeuffroy & Robin (1999), and were probably due to the fact that the highest N rate indicated the latest application time which coincides with the formation of spikelets per spike (Evans *et al.*, 1975).

### 1000 kernel weight (g)

In both seasons no significant differences were observed for different tillage methods on 1000 kernel weight (Fig.7.1), but higher values were recorded in 2000 compared to the 2001 season. This may be related to the larger number of kernels per spike produced in 2001 or due to the weather conditions (rainfall distribution and the temperature), which reduced the duration of grain filling during the 2001 season.



**Figure 7.2** Effect of crop rotation wheat/wheat (WW) and wheat/lupine/canola (WLWC) on number spikes per m<sup>2</sup>, spikelets per spike, seed per spikelet and 1000kernel weight (g) of spring wheat during the 2000 growing seasons at Langgewens Experimental Farm

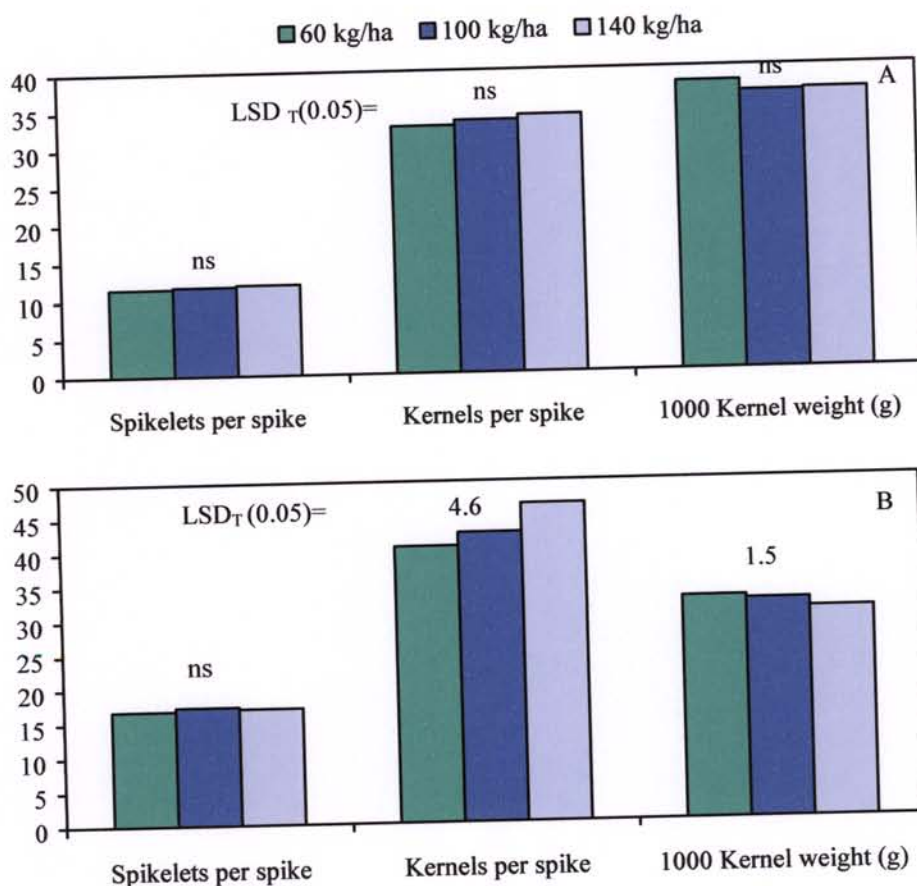
Again no significant differences were found between different crop rotations, but in general wheat produced in rotation with lupin and canola (WLWC) showed higher 1000 kernel mass compared to monoculture wheat (WW) (Fig. 7.2). In the 2000 season no significant differences were found between different rates of nitrogen application (Fig.7.3a). This may be due to dry conditions during this season. In the 2001 season, significant differences between different rates of N fertilisation were found. Higher 1000 kernel weight was obtained with 60 kg N ha<sup>-1</sup> compared to 100 and 140 kg N ha<sup>-1</sup> (Fig.7.3 b).

### Grain yield (kg per ha)



The mean grain yield for the years 1992, 1994, 1996 and 1998 as well as yields for the 2000 and 2001 growing seasons in response to tillage methods, crop rotation and different rates of nitrogen fertiliser are presented in Table 7.2.

Mean grain yield for the period 1992-1998 did not differ significantly as a result of different tillage methods, but significant differences due to tillage methods were found in both the 2000 and 2001 growing seasons. During the 2000 growing season, when the total rainfall was well below the long-term average, highest yields were produced where NT was applied. This may be due to better soil moisture conservation and greater water use efficiency with no-tillage under dry conditions (Lawrence *et al.*, 1994; Martinez *et al.*, 1995; Pratley 1995; Lafond *et al.*, 1996; Strong *et al.*, 1996; Halvorson *et al.*, 1999; DuBing *et al.*, 2000). The opposite was found in 2001, which was characterised by above average precipitation. In this year CT out yielded all other tillage treatments (Table 7.2). Similar trends were found for vegetative growth (Chapter 5) and yield components.



**Figure 7.3** Effect of different rates of nitrogen fertiliser on spikelets per spike, seed per spikelets and 1000 kernel weight (g) of spring wheat during the A) 2000 and B) 2001 growing seasons at Langgewens Experimental Farm

Crop rotation had a significant effect on the mean grain yield for the period 1992-1998, but not in 2000. Highest yields were produced when wheat was rotated with lupins and canola (WLWC). Similar results were reported by Heenan *et al.* (1994); López-Fando & Almendros (1995); Grace *et al.* (1995); Bationo & Ntare (2000) and Weisz *et al.* (2001). Significant tillage x crop rotation interaction for the mean grain yield (1992-1998 period) indicated that the performance of different tillage methods differed between crop rotations tested. When wheat was rotated with lupins and canola (WLWC), yields obtained with different tillage methods did not differ, but in the monoculture system (WW), yields obtained with CT were found to be significantly higher than with NT (Table 7.2). Although not significant, similar trends were found in 2000. These results indicated that intensive tillage methods like CT are needed in systems where wheat is grown in monoculture, while less intensive tillage systems and especially NT are better suited in systems where wheat

**Table 7.2** Effect of tillage methods, crop rotation and different rates of nitrogen fertiliser on the grain yield of spring wheat at Langgewens Experimental Farm

Tillage methods	N rate (kg ha <sup>-1</sup> )	Mean of 1992,94,96 &98			2000 season		2001 season	
		(WW)	(WLWC)	Mean	(WW)	(WLWC)	Mean	(WW)
CT	60	2665	2589	2627	2142	2078	2110	3106
CT	100	2504	2582	2543	2049	1911	1980	3341
CT	140	2397	2576	2486	2036	1732	1884	3328
Mean		2522	2582	2552	2076	1907	1991	3258
TT	60	2011	2436	2223	1852	2005	1929	1314
TT	100	2246	2774	2510	1988	2164	2076	2134
TT	140	2654	2772	2713	2110	2255	2183	2853
Mean		2304	2644	2475	1983	2141	2062	2100
MT	60	2188	2471	2329	1971	2357	2164	1312
MT	100	2314	2803	2558	1794	1883	1839	2108
MT	140	2447	2796	2621	1806	1674	1740	2601
Mean		2310	2690	2503	1857	1971	1914	2010
NT	60	1879	2360	2119	2281	2410	2346	1492
NT	100	2222	2744	2483	1839	2277	2058	2281
NT	140	2026	2717	2371	2068	2160	2114	2666
Mean		2042	2607	2324	2062	2282	2172	2146
G.Mean		2296	2631		1995	2075	2035	2379
Treatments		LSD <sub>T</sub> (0.05)			LSD <sub>T</sub> (0.05)		LSD <sub>T</sub> (0.05)	
Tillage		ns			198		157.5	
N-rate		192			ns		136	
Crop rotation		162			ns			
TN		218			ns		134.2	
TC		222			ns			
NC		ns			ns			
TNC		ns			ns			

CT conventional tillage, TT tine tillage, MT minimum tillage, NT no-tillage  
 TN tillage X nitrogen interaction, TC tillage X crop rotation interaction, NC nitrogen X crop rotation interaction, TNC tillage X nitrogen X crop rotation interaction

are rotated with broadleaf crops like lupins and canola. This trend is most likely due to the favourable effect of these crop rotations on soil nitrogen availability (Dala *et al.*, 1998; Galantini *et al.*, 2000), weed control (Triplett & Worsham, 1986), diseases (Boosalis, Doupnik & Atkins, 1986) and soil fertility in general (Grace *et al.*, 1995; López-Fando & Almendros, 1995), because it is well known that these factors may cause some problems in NT systems with monoculture (López-Bellido, López-Garrodo, Muentes, Castillo & Fernandez, 1997).

No significant differences were observed between different N rates in the dry season (2000) and the results even indicated a decrease in yield with increasing nitrogen rates.  $\text{NO}_3^-$ -N contents in the 0-300 mm soil profile at planting in the 2000 growing season were found to be equivalent to  $208.8 \text{ kg N ha}^{-1}$  (Chapter 4). These very high levels of residual-N in the soil at planting explain the absence of yield response to N fertiliser in this year. López-Bellido *et al.* (1996), also found an absence of yield response to different rates of nitrogen fertiliser in low rainfall years. In the 2001 season higher rates of nitrogen fertiliser resulted in higher grain yields. A similar tendency was found for the 1992, 1994, 1996 and 1998 seasons, resulting in mean values (1992-1998) for grain yield of 2325, 2524 and  $2548 \text{ kg ha}^{-1}$  for 60, 100 &  $140 \text{ kg N ha}^{-1}$  respectively. Nitrogen use efficiency ( $\text{kg grain produced per kg N applied}$ ) values of 34.8, 23.3 and 17.5 for the 60, 100 and  $140 \text{ kg N ha}^{-1}$  treatments respectively, however showed a decrease as nitrogen fertiliser rates increased. Similar trends were showed for N-use efficiency as  $\text{kg nitrogen in the vegetative plant per kg N applied}$  (Chapter 6), and were also found by López-Bellido & López-Bellido (2001). These results indicated that N supply was not the most important yield-determining factor in this study. Due to the large differences in response between years, it is clear that moisture supply were more important than N supply.

Significant tillage x N-rate interactions for the 1992-1998 period indicated that different tillage methods also responded differently to N-application rates. Where CT was used, yields did not increased with increasing N-rates. With TT, MT and NT yields did increase with increasing N-application rates (Table 7.2). Similar results were reported by Rao & Dao (1992) who found that cereals produced with reduced and no-tillage may require additional N fertiliser to reach production levels similar to those of conventional tillage.

## Conclusions

The results showed that the effect of the tillage systems on yield and yield components of spring wheat were largely affected by the climatic conditions, as experienced in a Mediterranean-type climate. On average yield did not vary much between tillage systems,

but results of individual years showed that in low rainfall years ( $\pm 250$  mm during the growth period), highest yields were obtained with no-tillage. In high rainfall years ( $\pm 450$  mm during the growth period), on the other hand, highest yield were obtained with conventional mouldboard tillage.

The results also suggested that under Mediterranean conditions no-tillage or minimum tillage should be combined with crop rotations to ensure that yields are comparable to that obtained with conventional tillage.

The response of wheat to nitrogen fertiliser rates also depends on the rainfall during the growth period. In this study wheat did not respond to nitrogen fertilisers in low rainfall years when rainfall was below 250 mm during the growth period. At rainfall of 450 mm nitrogen application rates of 100 to 140 kg N ha<sup>1</sup> may be needed to obtain maximum yields.

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## Chapter 8

### Effects of soil tillage, crop rotation and nitrogen application rates on grain quality parameters of spring wheat (*Triticum aestivum* L.) in the Swartland wheat producing area of South Africa

#### Abstract

Spring wheat (*Triticum aestivum* L.) is produced in the wheat producing areas of the Western Cape, Republic of South Africa, primarily for bread-making purposes. Milling and baking characteristics are therefore, of the utmost importance. The aim of this study was to determine the effect of method of tillage, crop rotation and N-fertiliser rates on bread-making characteristics in the above-mentioned wheat producing area. Milling characteristics such as flour yield were increased by conventional tillage in 2000, but hectolitre mass did not respond to tillage in 2000, or on average for the period 1992-1998. Although grain protein content and ultimately loaf volume was also higher with conventional tillage when compared to no-tillage, no-tillage resulted in the highest grain protein yield. This was due to the slightly higher grain yield obtained with no-tillage and the negative correlation between yield and quality found in several earlier studies. The inclusion of a legume crop (lupin) and canola in the rotation with wheat was found to have little effect on milling and baking characteristics in this study. This was most probably due to the fact that legumes were produced once in a four-year cycle only. Higher N-fertiliser rates ( $140 \text{ kg N ha}^{-1}$ ) resulted in reduced hectolitre mass, but higher grain protein when compared to low N rates of  $60 \text{ kg N ha}^{-1}$ . This study once more illustrated the complexity of the bread-making process and the need for good management practices in order to obtain both high yields and good bread-making quality under Mediterranean climatic conditions.

**Keywords:** Bread-making quality, crop rotation, method of tillage, N-fertiliser rates, spring wheat.

#### Introduction

Wheat grain quality is generally related to grain hardness and protein content and quality (Ivanov, Todorov, Stoeva, & Ivanova 1998; Stone & Savin, 1999). The unique dough-forming properties of wheat flour are primarily due to its protein constituents, especially



the gluten protein (Stone & Savin, 1999). Thus, protein content is the most important compositional attribute determining wheat market value and processing quality (Randall *et al.*, 1990; Gyori *et al.*, 1994; Agenbag, De Volder & Vlassak 1998).

The protein content is weakly heritable and mainly affected by nitrogen fertiliser application and other environmental and production parameters (Rao *et al.*, 1993; Nachit, Baum, Impiglia, Ketata, 1995; Novaro, Egidio, Bacci, & Mariani, 1997; Atli & Ekiz, 2000). However, Ivanov *et al.* (1998) found a significant difference in protein content of different cultivars.

According to Rao *et al.* (1993), López-Bellido, Fuentes, Castillo & López-Garrido (1998) temperature, rainfall and solar radiation during the grain-filling period are the climatic factors with the largest effects on protein concentration in wheat. Generally protein concentration in the grain increases with drought and decreases with abundant rainfall.

The effect of tillage methods on durum wheat quality is related to the soil characteristics and to the soil moisture at time of tillage as well as to the climatic conditions during grain filling (Pisante *et al.*, 2000). Tillage methods and crop rotation (including legume and fallow) may influence the protein content and bread-making quality of wheat because of their effect on moisture and nitrate content in the soil (Borghi *et al.*, 1995; López-Bellido *et al.*, 1998). Grain protein tends to be lower for no-tillage (NT) compared to conventional tillage (CT), but this was only true when no-tillage out yielded CT at the same N-application rate (Strong *et al.*, 1996). In contrast to this Blackshaw, Semach, Donovan & Harker (2000) found that wheat protein content was unaffected by tillage methods.

Crop rotations that included legumes are found to have beneficial effects on wheat grain quality when compared to continuous wheat, by improving the protein content and the rheological properties of the dough (López-Bellido *et al.*, 1998; Giambalvo *et al.*, 1999; Galantini *et al.*, 2000). This effect can be ascribed to the biological fixed residual N in the soil profile, which increase N supply and uptake by the wheat crop.

Protein and gluten content in the wheat grain and flour are increased by both application rate (Randall *et al.*, 1990; Zentner, Bowren, Edwards, & Campbell, 1990; Ayoub, Guertin, Fregeau-Reid & Smith, 1994; Gyori *et al.*, 1994; Agenbag *et al.*, 1998; Lomako, 1998) and time of application using a top-dressing of nitrogen (Nakatsu, Watanabe & Okumura, 1999).

Lapa, Bosak, Germanovich, & Golovach (1998) found that an additional 30 kg N ha<sup>-1</sup> at the beginning of the booting stage increased protein and gluten content of the wheat grain by 0.8 and 3.9% respectively. Although nitrogen input improved the grain quality generally, it was found to be more effective on sandy compared to clayish soils (Storozhenko & Kamil, 1999).

Ivanov *et al.* (1998) found a significant correlation between the total protein content and the loaf volume, while the correlation between total protein content and the mixing time were also evident but not significant. Dough mixing was found to be dominantly affected by growth conditions while dough strength related to protein quality (Bergman *et al.*, 1998).

At present little is known about the effect of agricultural practices on spring wheat quality parameters in South Africa. Thus, the objective of this study was to determine the effect of tillage methods, crop rotation and nitrogen fertilisation rates on grain quality parameters of spring wheat.

## **Materials and Methods**

Studies on spring wheat grain quality parameters (hectolitre mass, flour yield, grain and flour protein contents, gluten content, dough development time, Alveograph and micro bread loafs volume) were conducted during the 2000 growing seasons as part of a long-term tillage and crop rotation trial, and some of these quality parameters were compared with long-term averages for the 1997- 2000 period. Although the tillage treatments tested were initiated in 1976, present crop rotations and nitrogen application rates were only applied since 1990. Locality, climate, experimental layout and treatments as well as data analysis are discussed in Chapter 3.

In order to determine the effect of method of soil tillage, crop rotation and N-fertiliser rates on bread making quality, the following measurements were used.

Representative seed samples of approximately 2 kg each were collected from the final yield of each sub-plot and subjected to the following quality tests:

- i) Hectolitre mass was determined according to the standard Two Level Funnel Method.
- ii.) Grain and flour protein contents were determined by Near Infra-Red Spectroscopy (Technikon Infraalyzer 400). Protein yield was calculated by multiplying grain protein content with the grain yield (Chapter 7).
- iii.) Flour yield and bran were determined on 100-gram samples (14% moisture), using a Brabender Quadrumat Senior mill.
- iv.) Gluten content was determined according to AACC approved method 56-61A (AACC 1983).
- v.) Dough development time of the flour and resistance of dough to mixing were measured and recorded by using the mixograph method.
- vi.) The Alveograph was used to determine the rheological properties of dough prepared from flour and water, by measuring the pressure needed to blow a bubble in a sheated

piece of dough. The pressure required for each bubble is recorded and presented in graphical form as an "alveograph" (Borghi *et al.*, 1995). The maximum height of the curve provides an estimate of dough tenacity (P) and its length is a measure of dough extensibility (L). To be suitable for bread making, wheat should have a tenacity-extensibility ratio (P/L) of less than 1.0. Finally, the area (W) under the curve (cm<sup>2</sup>) as measured with a planimeter, multiplied by a factor of 6.54 (Nel, Agenbag & Purchase, 1999), indicates the energy required to cause the test piece (or dough bubble) to burst. This value is called alveograph index and is closely related to the strength of the dough (Faridi & Rasper, 1987).

vii.) Micro bread loafs were baked from 10 g flour using the baking formula developed by Shogren & Finney (1984). After it was cooled down at room temperature (25 °C), the volume was estimated through the displacing of the rape seeds (Shogren & Finney, 1984). In the case of grain protein content and hectolitre mass, values for 2000 were compared with long-term (1992-98) averages. For all other parameters data was available for the 2000 harvest only.

## Results and discussion

### Milling characteristics

#### Hectolitre mass

Although wheat quality is positively related to both protein content and quality (Ivanov *et al.*, 1998), hectolitre mass, which gives an indication of expected flour yield, is also of economic importance. In South Africa a minimum hectolitre mass value of 74 kg hl<sup>-1</sup> for wheat is required for bread-making purposes. In this study the average hectolitre mass for wheat produced in 2000 was found to be 82.2 kg hl<sup>-1</sup>. Compared to the long-term average, hectolitre mass during this growing season was considered to be exceptional high (Table 8.1). Although the growing season was considered to be dry (Chapter 3) adequate rain during September and therefore, favourable conditions during the grain falling period most probably caused the high hectolitre mass. Nel, Agenbag & Purchase (1998) showed that hectolitre mass is more affected by growing conditions than cultivar, but hectolitre mass was not significantly affected by either tillage methods or crop rotation. These results are however, in contrast to those reported by López-Bellido *et al.* (1998) namely that hectolitre mass is significantly higher as result to no-tillage compared to conventional tillage. Regarding nitrogen application rates, no significant differences were also found, but generally, lower nitrogen rates resulted in the highest hectolitre mass, which were again

similar to the long-term averages (Table 8.1). López-Bellido *et al.* (1998) reported that wheat didn't respond to N fertiliser when rainfall was below 450 mm during the growing season in mediterranean-type climates. In this study rainfall for the 2000 growing season (250 mm) was well below that average. Randall *et al.*, (1990), however reported that late nitrogen applications produced a slightly higher test weight (hectolitre mass) indicating higher kernel density.

**Table 8.1** Hectolitre mass and flour yield as affected by tillage methods, crop rotation and nitrogen rates

Treatments	Hectolitre mass (Kg. hl <sup>-1</sup> ) 2000	Mean Hectolitre mass 1992-98 (Kg.hl <sup>-1</sup> )	Flour yield (%) 2000
Tillage method			
CT	82.0	78.0	73.2ab
TT	82.4	77.5	73.8a
MT	82.9	78.5	72.8bc
NT	81.7	78.5	72.5c
Mean	82.25	78.1	73
LSD <sub>T</sub> (0.05)	ns	ns	0.78
Crop rotation			
WW	82	78	73.1
WLWC	82	78	73.0
Mean	82	78	73
LSD <sub>T</sub> (0.05)	ns	ns	ns
Nitrogen rates (kg.ha <sup>-1</sup> )			
60	83	79.9a	73.3
100	82	77.8b	73
140	82	77.5b	72.8
Mean	82	78.4	73
LSD <sub>T</sub> (0.05)	ns	1.4	ns

CT= Conventional tillage, TT= Tine tillage, MT= Minimum tillage, NT=No-tillage  
WW= Wheat/Wheat, WLW C= Wheat/Lupin/wheat/Canola

### Flour yield

Flour extraction yield (%) refers to the process whereby the endosperm is separated from the bran. Therefore, flour extraction yield (FY) provides a useful measure of milling efficiency and the variation in FY likely results from inherent cultivar differences in amount of endosperm and the interaction between aleurone cells and the innermost cell of the endosperm (Bergman *et al.*, 1998). Nel, Agenbag & Purchase (1999) reported that flour yield is highly affected by environment, with no significant cultivar x environment interaction. On average FY range between 70 and 76% for hard and soft wheat cultivars (Bergman *et al.*, 1998).

Flour yield of 73% on average was obtained in this study, which is acceptable for milling purposes. Tillage methods had a significant effect on flour yield. TT and CT resulted in a

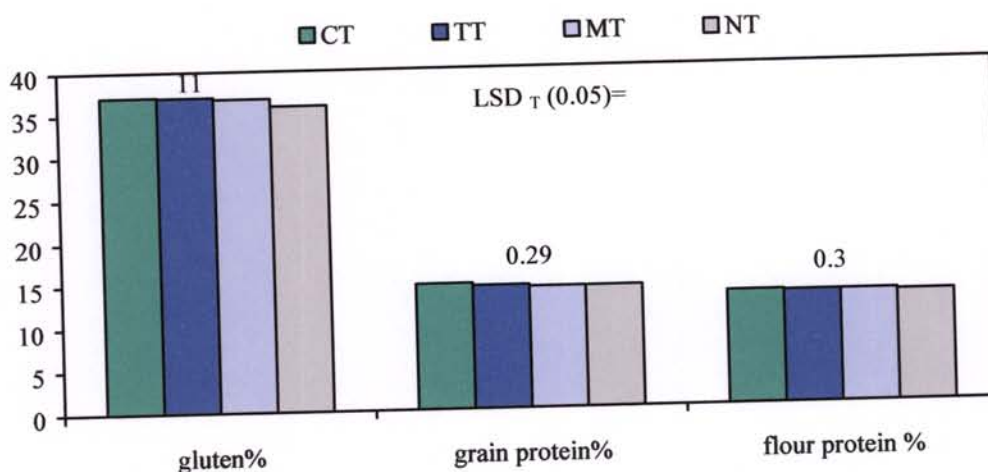


higher flour yield than MT and NT. The lowest flour yield was found for NT, which correlated with the slightly lower hectolitre mass. No significant effects on flour yield for either crop rotation or N fertiliser application were found (Table 8.1).

### Baking characteristics

#### Grain protein and flour protein content, gluten content and protein yield

Baking characteristics of wheat are primarily influenced by protein content and protein quality. Gluten provides excellent physical properties to the dough, (Ivanov *et al.*, 1998). Regarding the tillage treatments, grain and flour protein as well as gluten contents tended to be significantly lower for NT comparing with CT during the 2000 season. Trends were again similar to those observed for long-term averages (Fig. 8.1 & Table.8.2). These results are in agreement with those of Strong *et al.* (1996) and Løpez-Bellido *et al.* (1998), but in contrast to those of Blackshaw *et al.* (2000), namely that wheat protein content are unaffected by tillage methods.



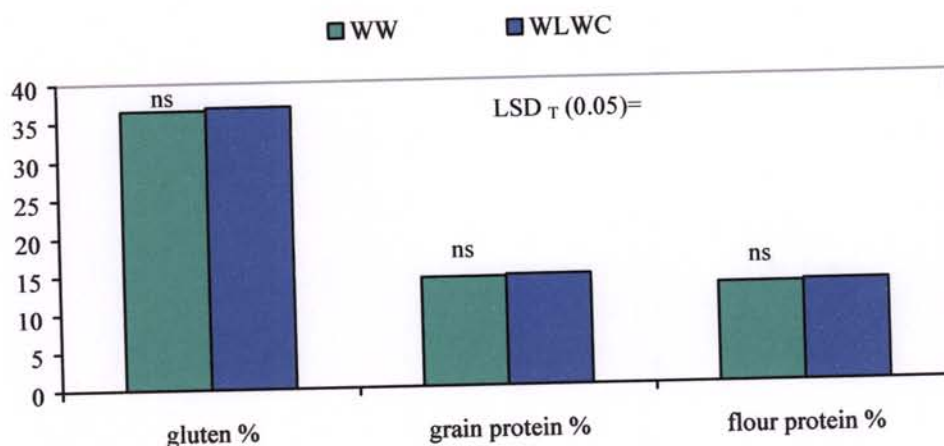
**Figure 8.1** Effect of conventional tillage (CT), tine tillage (TT), minimum tillage (MT), and no-tillage (NT) on gluten, grain and flour protein content (%) of spring wheat during the 2000-growing season at Langgewens Experimental Farm

Although grain and flour protein and gluten content were higher when lupin and canola were included in the crop rotation, differences were not significant in this study (Fig.8.2 & Table 8.2). The absence of significant differences are probably due to the improved soil physical conditions often found with crop rotations (Chan & Heenan, 1996), which resulted in higher yields and thus a dilution of grain protein (Stone & Savin, 1999). Similar results were reported by Giambalvo *et al.* (1999).

**Table 8.2** Protein yield ( $\text{kg ha}^{-1}$ ) and grain protein (%) as affected by tillage methods, crop rotation and nitrogen rates (mean values for the period (1992-98))

Treatments	Protein yield ( $\text{kg ha}^{-1}$ )	Grain protein (%)
Tillage method		
CT	290ab	11.7
TT	294ab	10.5
MT	270b	10.9
NT	306a	10.9
Mean	290	11
LSD <sub>T</sub> (0.05)	26.7	1.1
Crop rotation		
WW	283	11.0
WLWC	297	11.2
Mean	290	11.1
LSD <sub>T</sub> (0.05)	NS	NS
Nitrogen rates ( $\text{kg.ha}^{-1}$ )		
60	293	10.7
100	291	11
140	286	11.8
Mean	290	11.1
LSD <sub>T</sub> (0.05)	ns	0.9

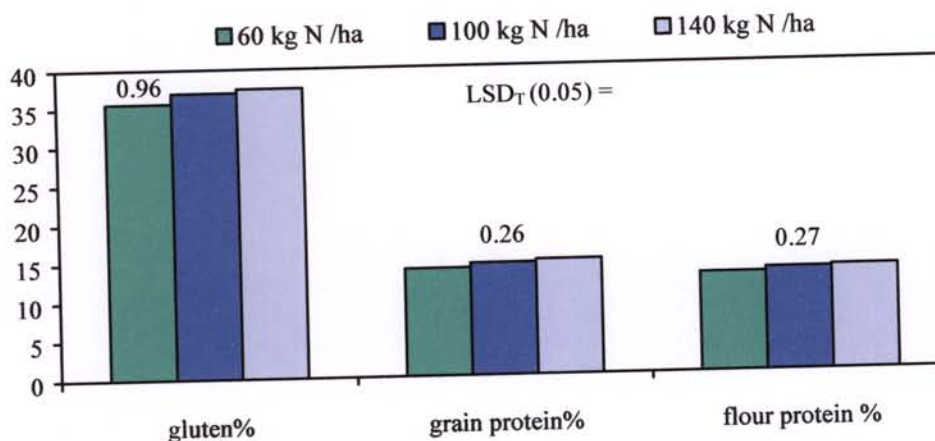
CT= Conventional tillage, TT= Tine tillage, MT= Minimum tillage, NT=No-tillage  
 WW= Wheat/Wheat, WLC= Wheat/Lupin/Canola



**Figure 8.2** Effect of wheat/wheat (WW) and wheat/lupin/wheat/canola (WLWC) crop rotation on gluten, grain and flour protein content (%) of spring wheat during the 2000-growing season at Langgewens Experimental Farm

High N fertiliser rates significantly increased the grain protein, flour protein and gluten contents during the 2000-growing season (Fig.8.3), when the rainfall was below average and the daily temperature higher than long-term average (Chapter 3). Grain and flour protein as well as gluten contents at a fertiliser rate of  $140 \text{ kg N ha}^{-1}$  were 14.8%, 13.4% and 37.5% respectively, compared to values of 13.9%, 12.7% and 35.6% at a fertiliser rate of  $60 \text{ kg N}$  respectively (Fig. 8.3).





**Figure 8.3** Effect of different N fertiliser rates on gluten, grain and flour protein content (%) of spring wheat during the 2000-growing season at Langgewens Experimental Farm

A similar trend was found for the long-term average of grain protein (Table 8.2). This finding is in agreement with the results of Randall *et al.* (1990), Zentner *et al.* (1990), Gyori *et al.* (1994), Agenbag *et al.* (1998) and Lomako (1998) who reported that nitrogen fertiliser increased protein and gluten content in the wheat kernel and flour.

Because of the negative correlation often found between grain yield and protein content (López-Bellido *et al.* (1998) and Stone & Savin, 1999), protein yield (percentage protein multiplied by grain yield) is regarded as a better indication of nitrogen availability or nitrogen use. In this study NT yielded 306 kg protein ha<sup>-1</sup> compared to 294, 290 and 270 kg protein ha<sup>-1</sup> for TT, CT and MT respectively (Table 8.2). Crop rotation (WLWC) yielded 297 kg protein ha<sup>-1</sup>, compared to 283 kg protein ha<sup>-1</sup> for WW, while increasing nitrogen application from 60 to 140 kg ha<sup>-1</sup> caused a decrease in protein yield from 293 to 286 kg protein ha<sup>-1</sup>. These differences were, however, not significant, indicating that nitrogen supply was not the main limiting factor. The absence in significant differences between treatments should therefore be attributed to climatic conditions such as the below average rainfall during growing season.

#### Alveograph index and Tenacity–extensibility ratio

Alveograph index (W) is considered to be closely related to the flour strength, while the W value illustrated the difference in dough strength with time during the mixing process. In this study the W-value was affected by tillage methods, crop rotation and nitrogen fertilisation. Highest W value of (292 cm<sup>2</sup>) was obtained by CT followed by NT (276 cm<sup>2</sup>), while TT and MT resulted in lowest values (Table 8.3). Crop rotations, which included lupin and canola, resulted in higher W values (284 cm<sup>2</sup>) compared to continuous wheat (272 cm<sup>2</sup>). The nitrogen fertiliser rate also had significant effects on W values. From

Table 8.3 it is clear that, the alveogram index increased with increasing the nitrogen fertiliser's rates, but no significant differences were found between 100 kg N ha<sup>-1</sup> and 140 kg N ha<sup>-1</sup> (Table 8. 3). These data supported findings by Randall *et al.* (1990).

**Table 8.3** Alveograph index (W), tenacity-extensibility ratio (P/L), dough development time (DT) and bread loaf volume (BLV) as affected by tillage methods, crop rotation and nitrogen rates during the 2000-growing season

Treatments	W (cm <sup>2</sup> )	P/L	DT (min)	BLV (cc)
<b>Tillage</b>				
CT	292a	0.4b	3.0a	67.0a
TT	271b	0.48a	2.8ab	63.4b
MT	273b	0.49a	3a	63.5b
NT	276ab	0.5a	2.7b	64ab
Mean	278	0.47	2.9	64
LSD <sub>T</sub> (0.05)	17.05	0.04	0.28	2.11
<b>Crop rotation</b>				
WW	272b	0.45b	2.9	64.1
WLWC	284a	0.49a	2.8	64.8
Mean	278	0.47	2.9	64
LSD <sub>T</sub> (0.05)	12.0	0.03	ns	ns
<b>Nitrogen rates (kg.ha<sup>-1</sup>)</b>				
60	257b	0.46	2.6b	64.4
100	284a	0.47	2.9a	64.5
140	295a	0.48	3a	64.4
Mean	278	0.47	2.9	64
LSD <sub>T</sub> (0.05)	14.8	ns	0.24	ns

CT= Conventional tillage, TT= Tine tillage, MT= Minimum tillage, NT=No-tillage  
WW= Wheat/Wheat, WLW C= Wheat/Lupin/wheat/Canola,

In this study P/L values ranged from 0.4 to 0.5, which are well below the maximum value of 1.0 required to be acceptable for dough and bread-making quality (Table 8.3). Although P/L values for NT were significantly higher than for CT, these higher values are not necessarily an indication of better quality and may be even worse if the effect of NT on other parameters like dough developments time, bread loaf volume, alveograph index and protein content are taken in consideration. Crop rotation also resulted in a significant higher P/L value compared to continuous wheat. No significant differences were however found between N-fertiliser rates.

#### Dough development characteristic

##### Dough development time

Dough development time relates to changes occurring in gluten protein during mixing (Ayoub *et al.*, 1994) was found to be longer with CT and TT compared to NT (Table 8.3). These findings are in agreement with L pez-Bellido *et al.* (1998), who attributed



differences between tillage methods to their effect on soil moisture and soil nitrate content. In contrast to Blackshaw *et al.* (2000), crop rotation had no effect on dough development time in this study. This was expected, as crop rotation did not have any effect on grain protein content.

Dough development time increased with increasing N rate in this study, with significant higher values found for applications of 100 and 140 kg N ha<sup>-1</sup> compared to 60 kg N ha<sup>-1</sup>. This correlates with higher grain protein contents found for these rates (data not shown).

#### Bread loaf volume

Bread loaf volume gives an indication of the gas retention capacity of the dough during the fermentation process, and it is more effected by the environment than by the cultivar (Nel, Agenbag & Purchase, 1999). Bread loaf volume (BLV) was affected by tillage methods with the highest loaf of volumes 67 cc found with CT (Table 8. 3). This correlates with the trend found for protein and gluten content. As shown for protein content, crop rotation did not affect loaf volume. Although high nitrogen application rates resulted in higher protein content, no differences in loaf volume were however found.

### Conclusions

Hectolitre mass was found to be very high for this study and the results showed that the tillage methods, crop rotation and nitrogen rates had no significant effect on the hectolitre mass. Grain and flour protein as well as gluten contents tended to be significantly higher for CT compared to NT. Dough development time was increased by CT and TT compared to NT, while bread loaf volumes tended to be higher for CT compared to NT. These results confirmed the negative correlation between yield and quality because NT resulted in a higher yield during 2000. Protein yield (percentage protein multiplied by grain yield) which is regarded as a better indication of nitrogen availability or nitrogen use showed that NT yielded 306 kg protein ha<sup>-1</sup> compared to 294, 290 and 270 kg protein ha<sup>-1</sup> for TT, CT and MT respectively.

Although grain protein, flour protein and gluten content were slightly higher when lupin and canola were included in the crop rotation, differences were not significant. The absence of significant differences are probably due to the fact that improved soil physical conditions found with crop rotations, most often result in higher yields and not improved grain quality. Crop rotations, which included lupin and canola, also resulted in higher W values compared to continuous wheat, but did not have an effect on dough development time.

High N fertiliser rates significantly increased the grain protein, flour protein and gluten contents. The nitrogen fertiliser rate also had significant effects on W values, clearly illustrating the positive effect of grain protein on this characteristic. Dough development time increased with increasing N rate, with significant higher values found for applications of 100 and 140 kg N ha<sup>-1</sup> compared to 60 kg N ha<sup>-1</sup>.

In conclusion it can be said that although production technique such as methods of tillage and N-fertiliser rates do have effect on grain wheat quality, results may vary between years due to the already known dominant effect of climatic conditions such as rainfall and temperature.

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## Chapter 9

### Summary

In the republic of South Africa the majority of spring wheat (*Triticum aestivum* L.) produced in the Swartland (Western Cape Province) is grown under rainfed Mediterranean-type climate, which is characterised by long, hot, dry summers and short wet mild winters with annual April to October rainfall that may vary from less than 250mm to more than 500mm. As also found in other Mediterranean type climates this large year to year variation and specially too little rain during the grain filling period is one of the most limiting factors of wheat production in the Swartland wheat producing area. In addition to that monocropping with wheat is used on more than 60% of all fields sown annually in this area, where soils are generally shallow sandy loams with a high gravel and stone content in the A-horizon. Very low organic C and total N content of the soil therefore hampered the already low production potential caused by the inadequate rainfall in combination with low water holding capacity of the shallow stony soils.

From literature it become clear that minimum or reduced tillage performs better than conventional tillage especially in years with below normal precipitation, due to better soil water conservation and higher water use efficiency, while the beneficial effect of crop rotation on wheat yield due to the increased amount of residual mineral-N in the soil and better water use efficiency is also well known. It was therefore argue that these techniques should help to improve yield potential and stability of crops in the Swartland wheat producing area.

For this reason a long term tillage study was started in 1976. Initial results showed that although reduced tillage (tine tillage and no-tillage) decreased the number of days that the crops were subjected to water stress, yields with reduced tillage were still lower compared with conventional tillage, however N-mineralisation rates were identified as one of the reasons for lower yields with reduced tillage. In 1990 the experiment was therefore changed to include crop rotation and N-fertiliser rates as treatments to determine whether the beneficial effect of legumes in combination with higher N-fertiliser rates will help to improve the feasibility of reduced tillage in this area.

The results of this study showed that differences in total mineral-N content of the soil were found between tillage treatments, crop rotations used as well as N-fertiliser rates applied.

Response however, varied largely between years due to annual variation in especially total precipitation and distribution of rainfall. Although conventional tillage resulted in higher mineral-N content in the soil at planting (before any fertiliser was applied), no large differences were found during the growth period. The effect of crop rotation, which includes lupins, was also surprisingly small, probably due to the fact lupins were grown once in a four year cycle only. N fertiliser, as expected, did result in higher mineral-N contents in the soil, but these levels did not last for long periods due to either N-leaching or plant up-take. To ensure sufficient mineral-N levels, late application of N-fertiliser will therefore be needed.

Although crop growth and N-content of plant components generally correlates with the above mentioned differences in mineral-N content of the soil, differences in year to year rainfall again caused contrasting results in dry and wet years.

Grain yields also differed between years due to rainfall, but clearly showed that the feasibility of reduced tillage in the Swartland area is largely dependant on the use of a well balanced crop rotation system. In a system of monoculture wheat yields with reduced tillage were found to be less than that with conventional tillage in most and specially high rainfall years, irrespective of fertiliser rate. In dry years (< 350 mm rainfall) reduced tillage yielded as well as or better than conventional tillage. In the crop rotation system, which includes canola and lupins, reduced tillage yielded as well as or better than conventional tillage. Although higher N-rates were needed when reduced tillage (especially no-tillage) is practised, this is probably due to the fact that lupins were planted once in a four year cycle only. Wheat quality parameters also showed some differences due to the tillage, crop rotation and N-fertiliser treatments. It however become clear that these differences were not directly related to the treatments, but in response to the effect of the treatments on grain yields, confirming the generally known negative correlation between yield and quality.

The results of this study showed that reduced tillage (especially minimum and no-tillage) may help to improve yield potential and stability of wheat in the Swartland area. Best results will be obtained in drier areas and when reduced tillage is used in combination with crop rotation systems, which includes non-cereal and preferably legumes crops. In high rainfall areas the use of crop rotations is essential when reduced tillage is practiced. Although the line between high and low rainfall is not very clear it seems to be approximately 350 mm during the growth period.

Distribution of rainfall will also be important and more research in this regard is needed in order to develop guidelines for the use of reduced tillage in the Swartland area. More research is also needed with regard to N application rates and timing, because the results showed a low mineral-N content in the soil during the grain filling period of the wheat and also low N-use efficiencies, which may have an effect on wheat quality in high yielding years.